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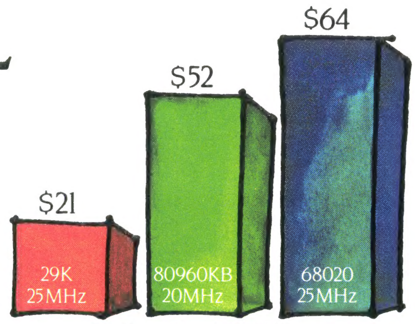

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CIRCLE NO 146

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Tough enough to pass stringent MIL-STD-883 tests, useable from dc to 6GHz and smaller than most RF switches, Mini-Circuits' hermetically-sealed (reflective) KSW-2-46 and (absorptive) KSWA-2-46 offer a new, unexplored horizon of applications. Unlike pin diode switches that become ineffective below 1MHz, these GaAs switches can operate down to dc with control voltage as low as -5V, at a blinding 2ns switching speed.

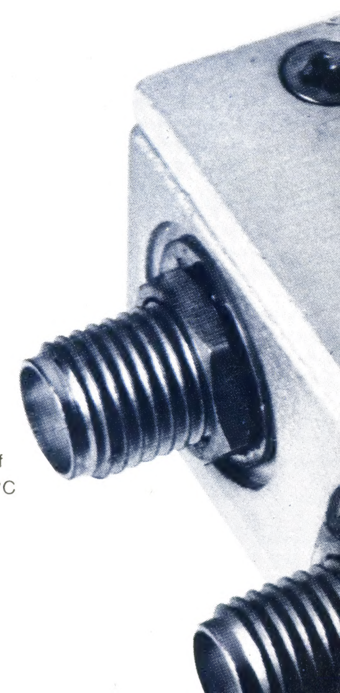
Despite its extremely tiny size, only 0.185 by 0.185 by 0.06 in., these switches provide 50dB isolation (considerably higher than many larger units) and insertion loss of only 1dB. The absorptive model KSWA-2-46 exhibits a typical VSWR of 1.5 in its "OFF" state over the entire frequency range. These surface-mount units can be soldered to pc boards using conventional assembly techniques. The KSW-2-46, priced at only $32.95, and the KSWA-2-46, at $48.95, are the latest examples of components from Mini-Circuits with unbeatable price/performance.

Connector versions, packaged in a 1.25 x 1.25 x 0.75 in. metal case, contain five SMA connectors, including one at each control port to maintain 3ns switching speed.

Switch fast... to Mini-Circuits' GaAs switches.

SPECIFICATIONS

Pin Model	**KSW-2-46**		**KSWA-2-46**	
Connector Version	**ZFSW-2-46**		**ZFSWA-2-46**	
FREQ. RANGE	dc-4.6 GHz		dc-4.6 GHz	
INSERT. LOSS (db)	typ	max	typ	max
dc-200MHz	0.9	1.1	0.8	1.1
200-1000MHz	1.0	1.3	0.9	1.3
1-4.6GHz	1.3	1.7	1.5	2.6
ISOLATION (dB)	typ	min	typ	min
dc-200MHz	60	50	60	50
200-1000MHz	45	40	50	40
1-4.6GHz	30	23	30	25
VSWR (typ) ON	1.3:1		1.3	
OFF	—		1.4	
SW. SPEED (nsec) rise or fall time	2(typ)		3(typ)	
MAX RF INPUT (bBm)				
up to 500MHz	+17		+17	
above 500MHz	+27		+27	
CONTROL VOLT.	-8V on, OV off		-8V on, OV off	
OPER/STOR TEMP.	-55° to +125°C		-55° to +125°C	
PRICE (10-24)	**$32.95**		**$48.95**	
	$69.95		**$79.95**	



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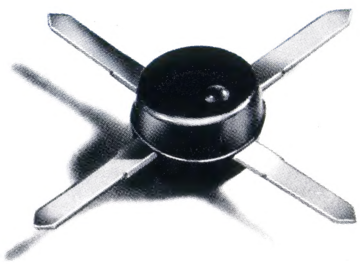
from 99¢



dc to 2000 MHz amplifier series

SPECIFICATIONS

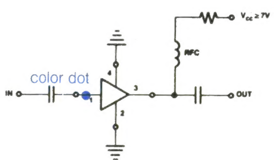
MODEL	FREQ. MHz	GAIN, dB 100 MHz	1000 MHz	2000 MHz	Min. (note)	• MAX. PWR. dBm	NF dB	PRICE $ Ea.	Qty.
MAR-1	DC-1000	18.5	15.5	—	13.0	0	5.0	0.99	(100)
MAR-2	DC-2000	13	12.5	11	8.5	+3	6.5	1.50	(25)
MAR-3	DC-2000	13	12.5	10.5	8.0	+8 □	6.0	1.70	(25)
MAR-4	DC-1000	8.2	8.0	—	7.0	+11	7.0	1.90	(25)
MAR-6	DC-2000	20	16	11	9	0	2.8	1.29	(25)
MAR-7	DC-2000	13.5	12.5	10.5	8.5	+3	5.0	1.90	(25)
MAR-8	DC-1000	33	23	—	19	+10	3.5	2.20	(25)

NOTE: Minimum gain at highest frequency point and over full temperature range.
• 1dB Gain Compression
□ +4dBm 1 to 2 GHz

designers amplifier kit, DAK-2

5 of each model, total 35 amplifiers

only $59.95



Unbelievable, until now...tiny monolithic wide-band amplifiers for as low as 99 cents. These rugged 0.085 in.diam.,plastic-packaged units are 50ohm* input/output impedance, unconditionally stable regardless of load*, and easily cascadable. Models in the MAR-series offer up to 33 dB gain, 0 to +11dBm output, noise figure as low as 2.8dB, and up to DC-2000MHz bandwidth.

*MAR-8, Input/Output Impedance is not 50ohms, see data sheet. Stable for source/load impedance VSWR less than 3:1

Also, for your design convenience, Mini-Circuits offers chip coupling capacitors at 12 cents each.†

Size (mils)	Tolerance	Temperature Characteristic	Value
80 × 50	5%	NPO	10, 22, 47, 68, 100, 470, 680, 100 pf
80 × 50	10%	X7R	2200, 4700, 6800, 10,000 pf
120 × 60	10%	X7R	.022, .047, .068, .1μf

† Minimum Order 50 per Value

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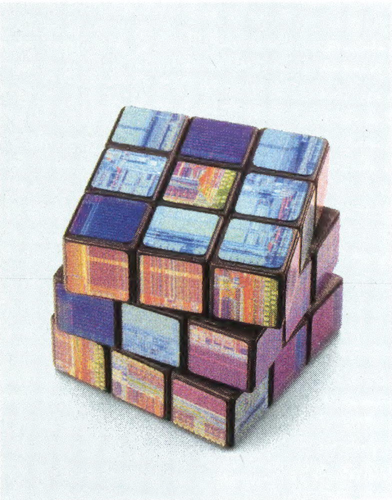
Volume 34, Number 3

EDN Magazine Edition

February 2, 1989

ELECTRONIC TECHNOLOGY FOR ENGINEERS AND ENGINEERING MANAGERS



On the cover: *Core microprocessors take the mystery out of designing a complete pc-board μP system onto a single IC. See pg 130. (Photo courtesy LSI Logic Corp)*

Continued on page 7

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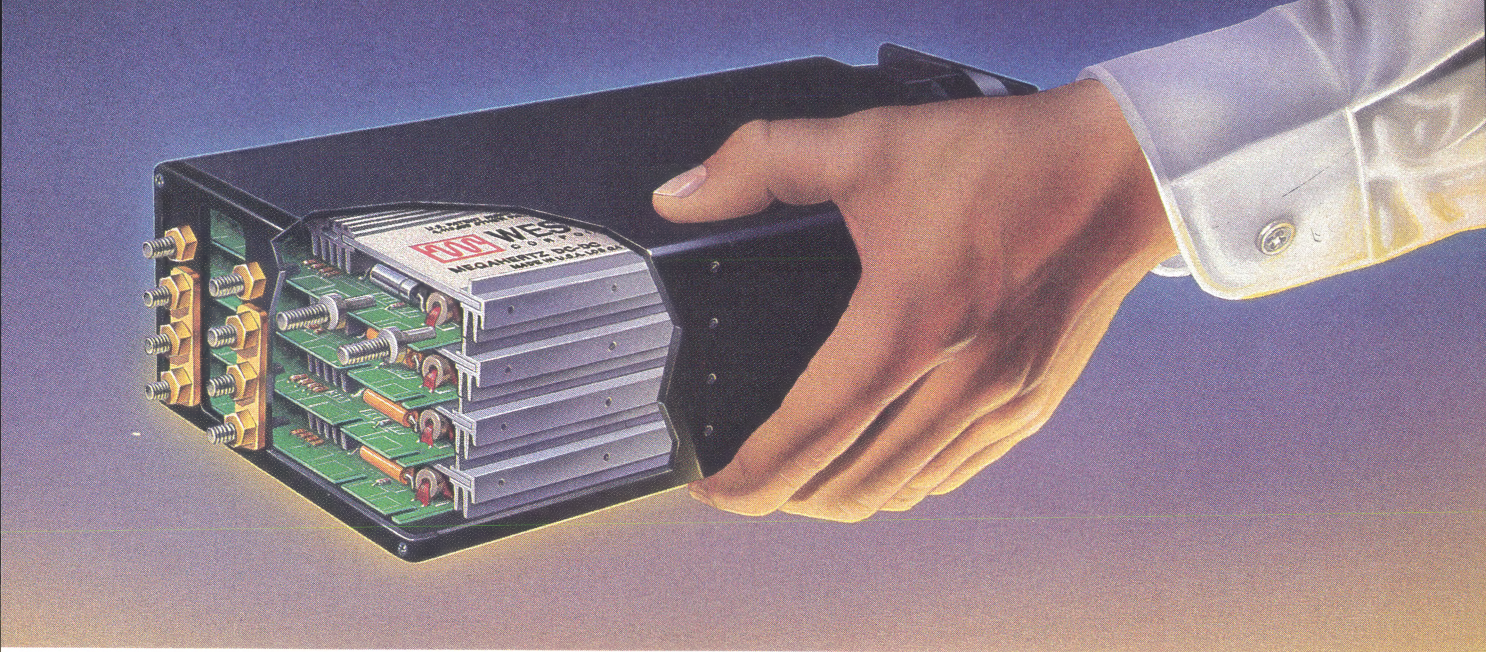

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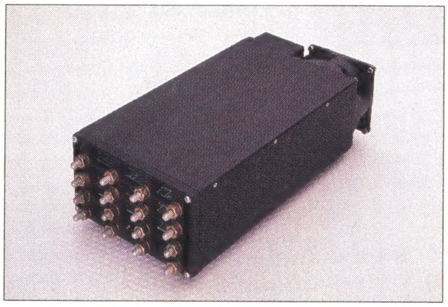
For existing designs the StakPak's small size and low profile allow system enhancement without mechanical redesign. Simply replace your open frame switcher with up to 1200 watts of StakPak power or replace your "box switcher" with 2 StakPaks and realize up to twice the power without losing additional space. StakPak power factor correction provides 850 watts of output power from a standard 115 VAC wall outlet. In new designs, more space can be devoted to functionality or the system can be downsized.

The StakPak's 8 module output section can be factory configured in virtually an infinite number of voltage, current and power combinations. Special models providing between 250 to 1200 watts and outputs from 2 to 95 VDC are available.

Other features include outstanding electrical performance; UL, CSA, VDE safety agency approval (in process); variable speed fan option for low ambient noise enviroments and 3 phase or DC input options. Indeed, with unprecedented power density, versatility and new features, the StakPak redefines power packaging. Please contact Westcor for a data sheet, pricing and additional information.



STANDARD 1200 WATT STAKPAK MODELS (110/220 VAC input)

Model	Output Voltage (VDC) and Maximum Current (amperes) per Channel #1	#2	#3	#4	#5
Single Output					
SP1-1801	2 @ 240				
SP1-1802	5 @ 240				
SP1-1803	12 @ 100				
SP1-1804	15 @ 80				
SP1-1805	24 @ 50				
SP1-1806	28 @ 42				
SP1-1807	48 @ 25				
Dual Output					
SP2-1801	2 @ 120	5 @ 120			
SP2-1802	5 @ 120	5 @ 120			
SP2-1803	5 @ 120	12 @ 66			
SP2-1804	12 @ 66	12 @ 66			
SP2-1805	15 @ 53	15 @ 53			
Triple Output					
SP3-1801	5 @ 180	12 @ 16	12 @ 16		
SP3-1802	5 @ 150	12 @ 33	12 @ 16		
SP3-1803	5 @ 180	15 @ 13	15 @ 13		
SP3-1804	5 @ 150	15 @ 26	15 @ 13		
Quad Output					
SP4-1801	5 @ 150	12 @ 16	12 @ 16	5 @ 30	
SP4-1802	5 @ 150	15 @ 13	15 @ 13	5 @ 30	
SP4-1803	5 @ 150	12 @ 16	12 @ 16	24 @ 8	
SP4-1804	5 @ 150	15 @ 13	15 @ 13	24 @ 8	
Five Output					
SP5-1801	5 @ 120	12 @ 16	12 @ 16	5 @ 30	24 @ 8
SP5-1802	5 @ 120	15 @ 13	15 @ 13	5 @ 30	24 @ 8

Total output power may not exceed 1200 watts for any model, single or multiple output. Lower power StakPak models are available. Please contact the factory.

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Continued from page 5

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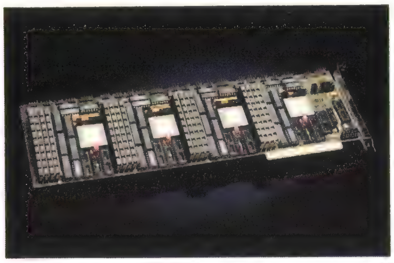

***The hardware design of Transputer-based add-in boards** is straightforward; it's the accompanying software that may determine which board is best for your needs (pg 59).*

TECHNOLOGY UPDATE

PRODUCT UPDATE

Continued on page 9

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Continued from page 7

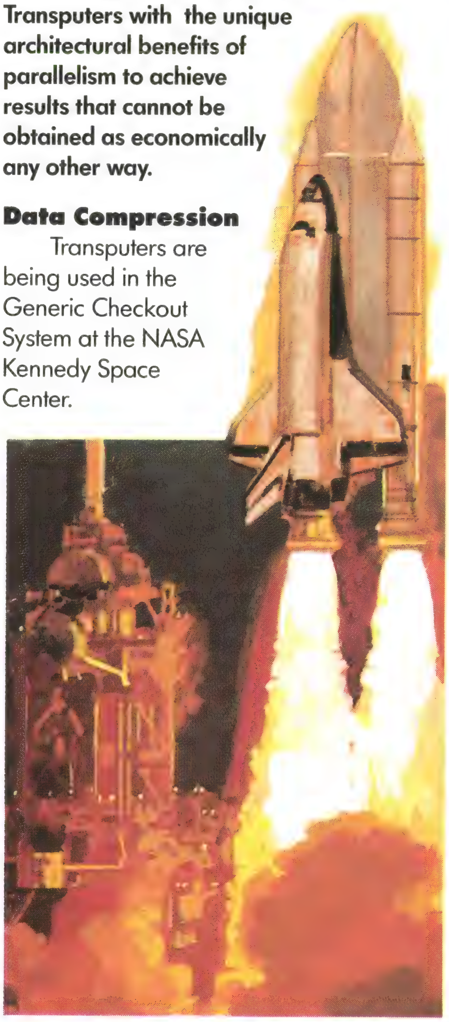
EDN Magazine Edition

February 2, 1989

“OK...SO THE TRA
BUT WHAT ABOUT

They're everywhere. Worldwide over a thousand Transputer designs are in today's marketplace or are entering production. Some belong to Fortune 500 companies committed to using Transputers to build their next-generation products.

Although Transputer applications are diverse, the theme for each is the same – combining the power of individual Transputers with the unique architectural benefits of parallelism to achieve results that cannot be obtained as economically any other way.



Data Compression

Transputers are being used in the Generic Checkout System at the NASA Kennedy Space Center.

They are embedded within VME based front-end Data Acquisition Modules to provide data filtering for the system.

These modules pre-process data for a network of Unix based workstations that provide real-time control and monitoring of ground and flight equipment, like that used by the Space Shuttle. Only Transputers offered the degree of parallelism needed for this application.

Medical Imaging

University College London is using the parallel processing power of Transputers to convert CAT, NMR and laser scans into rotating 3-D images. These facial, skeletal, and soft-tissue images provide accurate computerized measurements to assist doctors with each step of an operation, and are also used by plastic surgeons to 'rehearse' operations for reconstruction.

Data Collection

British Steel is implementing an intelligent system that is designed to dramatically cut its multimillion dollar annual energy costs. It is built around T800 floating point microprocessors which process information from a highly complex data gathering system. These Transputers operate in parallel, condensing enormous amounts of data into information which helps energy management decide how to respond to a plant's changing demands for different fuels.

Data Transmission

Kokusai Denshin Denwa (KDD), the Japanese international telecommunications company, has developed an image-processing video telephone using Transputers to manipulate and condense images for transmission over telephone links.

This image communications system uses 32 Transputers operating in parallel for ultrafast image processing. It can be connected to PC's to transmit images over telephone lines, function as a video phone, or be programmed to match the specifications of other receiving equipment, such as facsimile machines and TV monitors.

Space

The European Space Agency is using Transputers to build a light-weight, radiation-tolerant, on-board computer for spacecraft. Programs which utilize Transputers in scientific computing and spacecraft control applications are also being developed in the U.S.

Transputers are manufactured on epitaxial silicon and have been shown to withstand aggressive tactical radiation levels.

PUTER'S TERRIFIC, EAL APPLICATIONS?"

light Simulation

British Aerospace have used ransputers to develop a low-cost ight simulator comprising a flat vorld, ground-grid, buildings, rees and mountains – vith an optional Head-up display. Future enhancements vill include the addition of undulating errain and a single or triple window display option.

American companies are also using Transputers to build high-performance flight simulators more cheaply. One U.S. manufacturer utilizes over one thousand T800 processors per system.

3-D Rendering

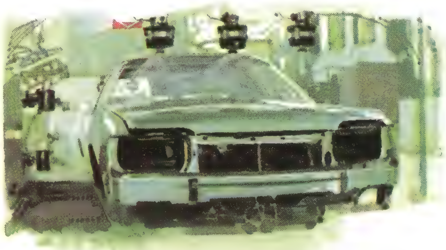
Pixar in the US has developed a Transputer-based rendering system which quickly renders photorealistic images from 3-D models. The system consists of Transputer boards for VME and AT-bus systems optimized to run Pixar's sophisticated rendering software.

The system holds great promise for such applications as architecture, automobile styling, package design, simulation as well as animation. Pixar's recent computer generated film 'Tin Toy' could not have been done without using this Transputer-based accelerator.

System Control

As the number of Transputers in a system design are increased, a proportional increase in performance can be achieved.

In West Germany, Parsytec GmbH is using this principle in their Megaframe Superclusters. Superclusters represent a complete series of reconfigurable industrial control boards as used in the automotive industry, which exploit the Transputer's parallel processing capability.



The basic Model 64, built with T800's, has a performance of 640MIPS and 96 MFLOPS. The Model 256 comprises four Model 64 cabinets connected by cables and provides 2,560MIPS and 384 MFLOPS.

Parsytec believes there is no limit to the size Superclusters can grow to. Two Model 256s can be combined easily to realize twice the raw performance of one system.

Robotics

Transputers are ideally suited for robotics applications because their special on-chip links make communication between control centers naturally easy. They are often used in the central control area for dumb robots, in multi-jointed robots, and in machine vision systems.

At the Houston Space Center, NASA and Lockheed are using Transputers in the development of an intelligent, self-manoeuvering, voice-controlled robot named EVA Retriever. EVAR is being built to investigate the autonomous retrieval of objects and astronauts that become detached from the Space Station.

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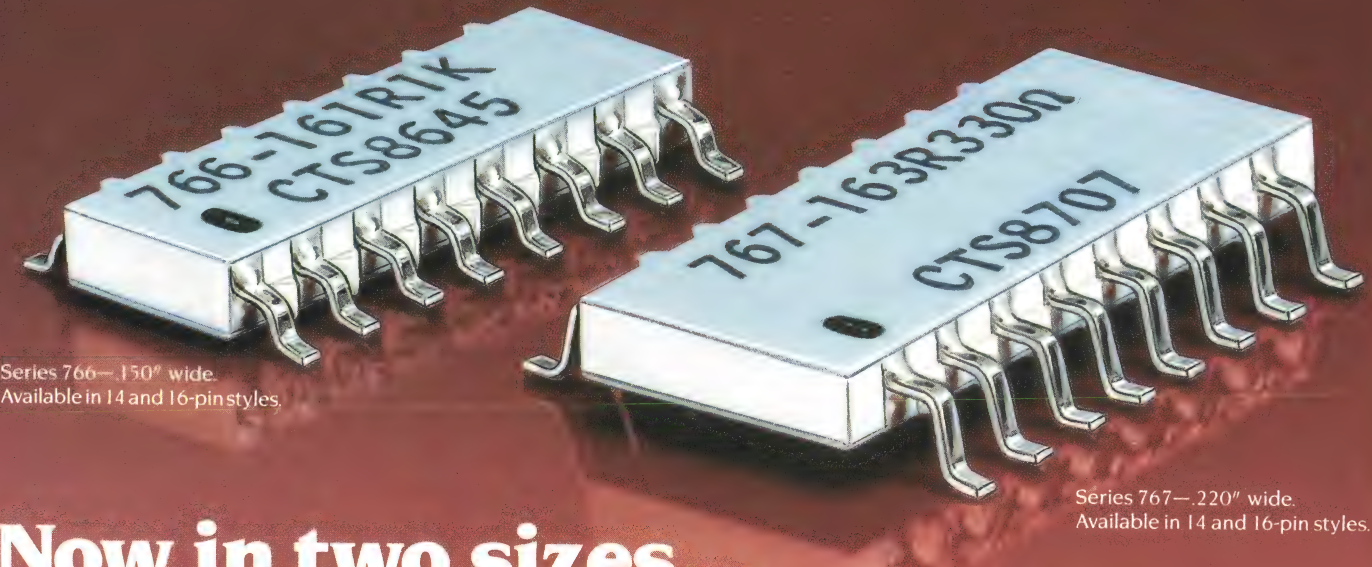

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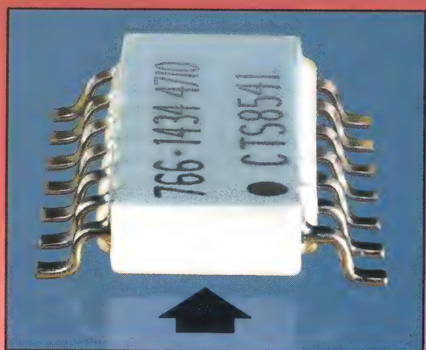

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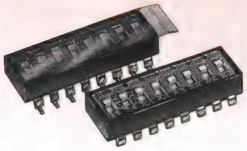

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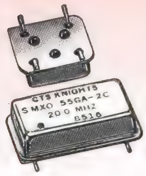

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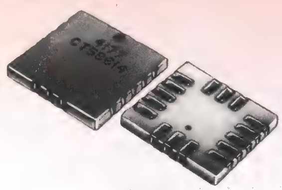

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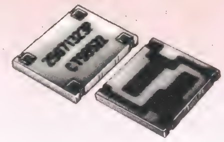

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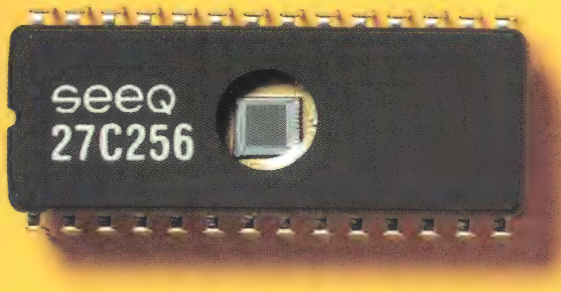

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The combination of our FLASH cell architecture and EEPROM-type erasure make possible this chip's fast erase speed. The 512K memory array is divided into 128 sectors of 512 bytes each. And each sector can be individually erased and reprogrammed. You can also remove the entire memory contents with chip erase. Typical erase time is 2 seconds. And write time is just 1ms per byte.

You can get our 512K FLASH in ceramic and plastic surface mount packages, as well as both plastic and

The electrical erasure of an EEPROM.

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You'll see that having it both ways is the best way.

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E^2 is our middle name.

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EDN

NEWS BREAKS

EDITED BY JOANNE DE OLIVEIRA

PC ADD-IN DATA-ACQUISITION BOARD INCLUDES DSP CHIP

PC-based data-acquisition systems are usually constrained by the PC's slow processing speed. The PC's microprocessor and the slow response time of MS-DOS can create a bottleneck for data-acquisition boards that acquire data at rates exceeding 150,000 samples/sec. Although these boards acquire data at high rates, the host can't process it in real time. The DAP 2400 add-in board from Microstar Labs (Redmond, WA, (206) 881-4286) doesn't rely on the host PC to process acquired data because it has an Intel 80186 μP and a Motorola DSP56001 DSP on board. The 80186 runs the company's proprietary DAPL operating system, which controls the sharing of the DSP by concurrent tasks. DAPL also provides predefined commands for DSP applications; you can command the board to perform DSP tasks such as FFTs and FIR filtering without writing any code.

With a 10-MHz 80C186 and a 20-MHz DSP56001 that has 2048 24-bit-wide words of static RAM, the board can perform a 512-point FFT and can support both an output update rate of 156,000 values/sec and a sampling speed of 156,000 samples/sec. The DAP 2400 costs $2800; it will be available in March. Boards with faster processors and faster update and sampling speeds are also available.
—Margery Conner

1-CHIP TOKEN-RING DEVICE OFFERS 16M-BPS PERFORMANCE

Integrating on one chip a number of token-ring communication functions that previously required five ICs, the TMS380C16 CommProcessor from Texas Instruments (Dallas, TX, (800) 232-3200 ext 700) also provides your network with 16M-bps IEEE-802.5 performance, protocol handling, bus-master DMA interfacing, PC-bus interfacing, and dynamic-RAM expansion. Fabricated in 1-μm CMOS, the TMS380C16 also supports the industry-standard 4M-bps token-ring communication rate. This chip lets you design an IBM-compatible token-ring adapter in less than 10 in^2 of space. Its 16-bit CPU executes the adapter firmware for the IEEE-802.5 Medium Access Control and IEEE-802.2 Logical Link Control protocols. The DMA interface sends data-transfer bursts to the host system at rates reaching 10M bytes/sec. This device also has a 2M-byte local address space with a direct interface for 256k-, 1M-, and 4M-bit dynamic RAMs. An extended 32-bit system address lets the chip access the entire memory space of host systems based on 80386, 68030, and RISC μPs. Packaged in a 132-pin JEDEC quad flat pack, the TMS380C16 sells for $96 (1000). A companion chip, the TMS38053 ring interface, sells for $24 (1000).—J D Mosley

SIMULATOR ADDS LOGIC SYNTHESIS

Ikos Systems (Sunnyvale, CA, (408) 245-1900) has added a variety of features to its simulation system with its latest version, release 3.0. For example, the system now allows you to make changes to your design without recompiling. This feature, called incremental logic synthesis, allows you to make changes directly to the net list, so you don't need to go back through schematic capture to correct minor errors. The new release also provides a vector-grading capability, which lets you determine the fault coverage provided by your test vectors. Release 3.0 will be included in all new orders and is available to current users who have maintenance contracts.
—Richard A Quinnell

NEWS BREAKS

IEEE 10-SLOT MAINFRAME PROVIDES 16-BIT DATA ACQUISITION

If you've been looking for a 16-bit data-acquisition mainframe that can handle as many as 6000 samples/sec and plugs into your computer's IEEE-488 port, consider the 556 Measurement and Control System from Keithley Instruments (Cleveland, OH, (800) 552-1115, TLX 985469). It costs $1395. You can plug as many as 10 data-acquisition module cards into the 556, thus freeing the expansion slots in your host computer for other applications. Compatible with any computer that has an IEEE-488 port, the 556 has its own μP for buffer control, module identification, and remote program execution. You can use the 556 to integrate your data-acquisition tasks with IEEE test equipment without learning a new programming language, because you program this mainframe with a set of more than 40 device-dependent commands that control such functions as memory management, hardware configuration, looping, and triggering. The 556 works with popular test software such as Asystant GPIB, Labtech Notebook, and LabView.—J D Mosley

SYNCHRONOUS 64k-BIT STATIC RAMs CLOCK 20-NSEC CYCLES

To meet the needs of systems with complex memory protocols, you can turn to the 20-nsec cycle times of the MCM629 family of 16k × 4-bit synchronous static RAMs from Motorola (Austin, TX, (512) 928-6700). The devices use on-chip I/O registers and transparent latches and sell for $55.16 (100) in plastic DIPs and $60.70 in plastic SOJ packages.—J D Mosley

QUANTUM-EFFECT TRANSISTOR EXHIBITS FSEC TRANSIT TIMES

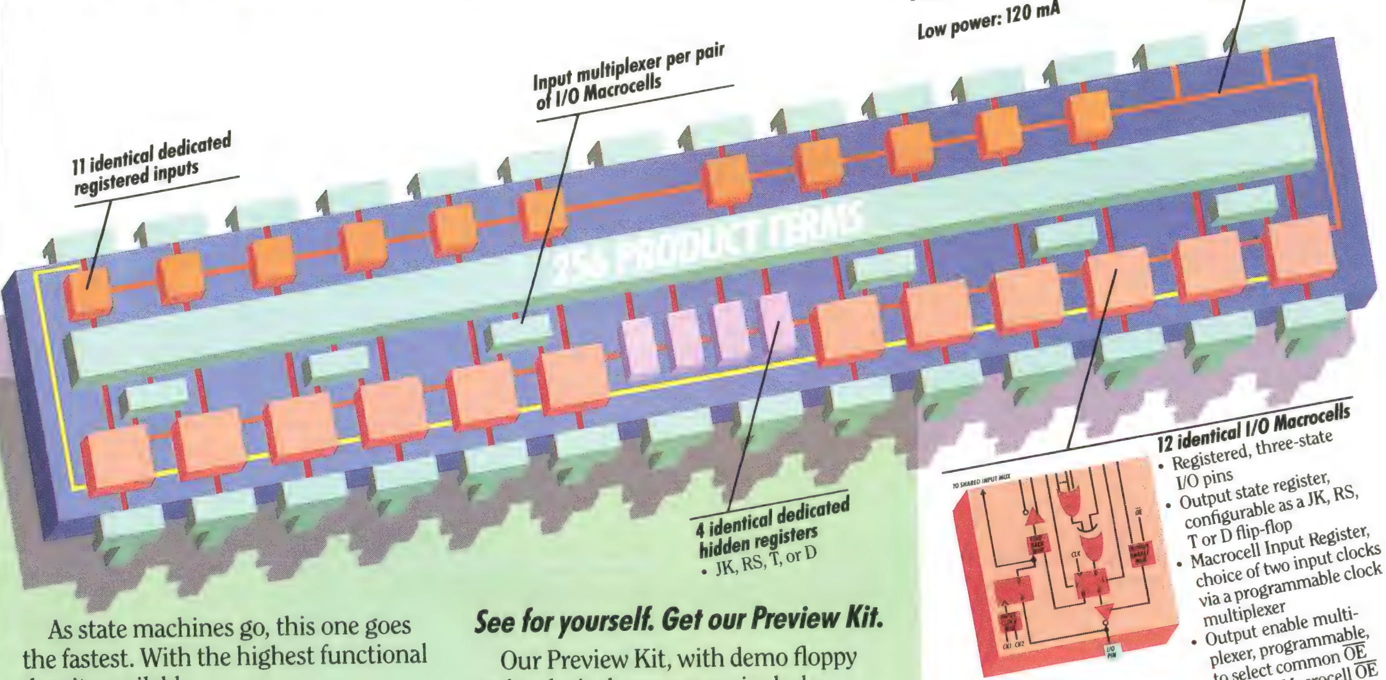
Research physicists at Texas Instruments Inc (Dallas, TX, (214) 995-6611) recently announced that they had succeeded in fabricating the first quantum-effect transistor. The device employs critical dimensions 100 times smaller and exhibits transit speeds 1000 times faster than conventional transistors, relying on resonant-tunneling effects for its operation. Because the device has active-region geometries on the order of 10 to 20 nm, only electrons at resonant energy levels can tunnel from the emitter through the transistor's base to the collector.

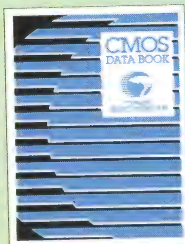
The existing devices, called "bipolar resonant-tunneling transistors," employ an extremely thin, 2-dimensional, quantum-well base electrode and exhibit base-region transit times of a few femtoseconds and typical current gains of 50. Future research will focus on the development of a unipolar device that uses quantum effects to constrain electrons in three dimensions—a so-called quantum-dot device. Ultimately, the company plans to use resonant-tunneling devices to build extremely fast circuits that consume very little power. As Dr George Heilmeier (senior vice president and chief technical officer at TI) quipped, "One day, we might see a laptop supercomputer that runs on flashlight batteries."—Steven H Leibson

HIGH-SPEED OP AMP FEATURES TWO PAIRS OF INPUTS

For analog applications that must switch between two input signals, the 16-pin OPA675 and OPA676 wideband op amps from Burr-Brown (Tucson, AZ, (602) 746-1111) feature two pairs of differential inputs. The OPA675 has a TTL-compatible input-selection pin; it switches between its analog-input signal pairs in 6 nsec. The OPA676 has an ECL-compatible selector; it switches in 4 nsec. Both op amps achieve 185-MHz bandwidths when set to a closed-loop voltage gain of 10, and both settle to within 1% of a final value in 9 nsec. (All specifications are typical numbers.) The op amps cost $19.35 (1000).—Steven H Leibson

Why high performance designers are so excited about the new PLD 7C330 State Machine:





NEWS BREAKS: INTERNATIONAL

SOLID-STATE CAMERA ASSEMBLY SEES IN STARLIGHT

By coupling a solid-state image sensor to an image intensifier, Philips' Components Div (Eindhoven, The Netherlands, TLX 35000; in the US, Amperex Corp, Slatersville, RI, (401) 762-9000) has produced a video camera assembly that can operate in lighting conditions as low as 10^{-4} lux, which is equivalent to overcast starlight. To develop a complete black-and-white video camera with the assembly, you need only add drive electronics and a chassis. In addition to its obvious uses in surveillance and high-speed machine-vision systems, the camera is suitable for use in scientific applications—for example, in astronomical, medical, spectroscopy, and fluorescence-detection equipment.

The light output from the image intensifier is coupled to the solid-state image sensor via a tapered fiber-optic bundle. As a result, the picture quality is maintained right into the corners of the image, and the assembly is highly resistant to shock and vibration. The assembly is 43 mm long and 44 mm in diameter, and it weighs 115g. The image it produces has a distortion level of 0.1% and a horizontal resolution of 21 line pairs per millimeter. The unit is available in versions that conform to CCIR or EIA TV standards, and it costs around gld 10,000 in large quantities. For evaluation purposes, a complete camera is available for gld 20,000.—Peter Harold

BOARD PROVIDES MIXED I/O FOR MULTIBUS II SYSTEMS

Taking full advantage of the area available on an extended double-Eurocard board, the IO-186/070 intelligent I/O board for Multibus II systems provides a combination of analog and digital I/O functions. Manufactured by Concurrent Technologies (Colchester, UK, FAX 0206-67333; in the US, San Diego, CA, (619) 592-1479), the board provides 16 single-ended or eight differential analog input channels, six analog output channels, and 48 digital I/O lines.

The analog inputs are digitized by a 12-bit A/D converter with a conversion time of 5 μsec, and the analog outputs are driven by six separate 12-bit D/A converters with output settling times of 1.5 μsec. The analog inputs and outputs operate over 0 to 10V or 0 to −10V. The digital I/O is TTL compatible. Subsystem intelligence is provided by an 80186 μP with as much as 512k bytes of EPROM and as much as 512k bytes of dual-ported static RAM. The board's Multibus II interface supports message passing, built-in self-test, and interconnect space functions, and the board also carries the company's cCBX interface for subsystem expansion. The IO-186/070, which costs around $2700, will be launched in the US at Buscon West (Santa Clara, CA, February 6 to 9, 1989).—Peter Harold

MEMORY WILL OFFER 0.59-NSEC ACCESS AND RUN ON 0.09W

According to reports in the Japanese press, Fujitsu has begun to produce samples of a 4k-bit Josephson memory, which will offer an access time of 0.59 nsec and will run on 0.09W. By comparison, a silicon-based memory device of approximately the same size offers 2.3 nsec and runs on 1.6W, and a GaAs memory has a 10-nsec access time and runs on 0.2W. The memory puts 14,468 Josephson devices into a 7.7-mm square. The part is at least a 4-μm design at present, but Fujitsu expects to be able to reduce the width to that of silicon parts. The company also projects further improvement in the device's performance.—Joanne De Oliveira

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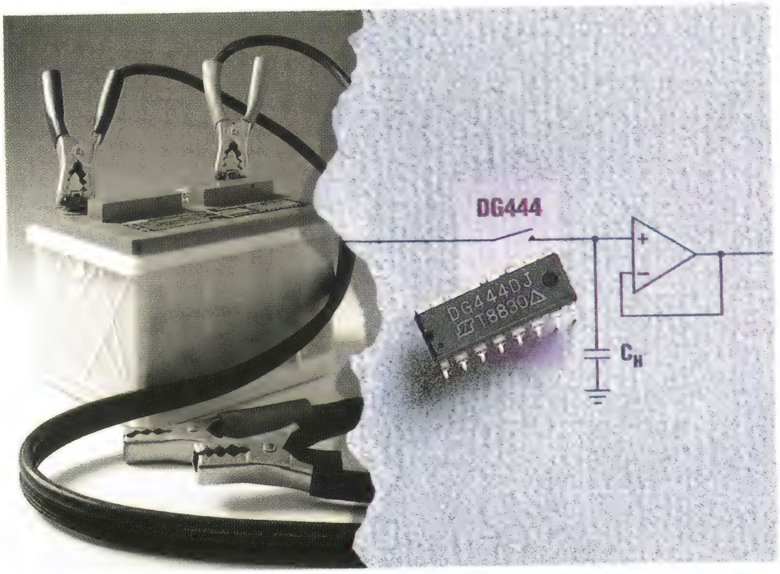

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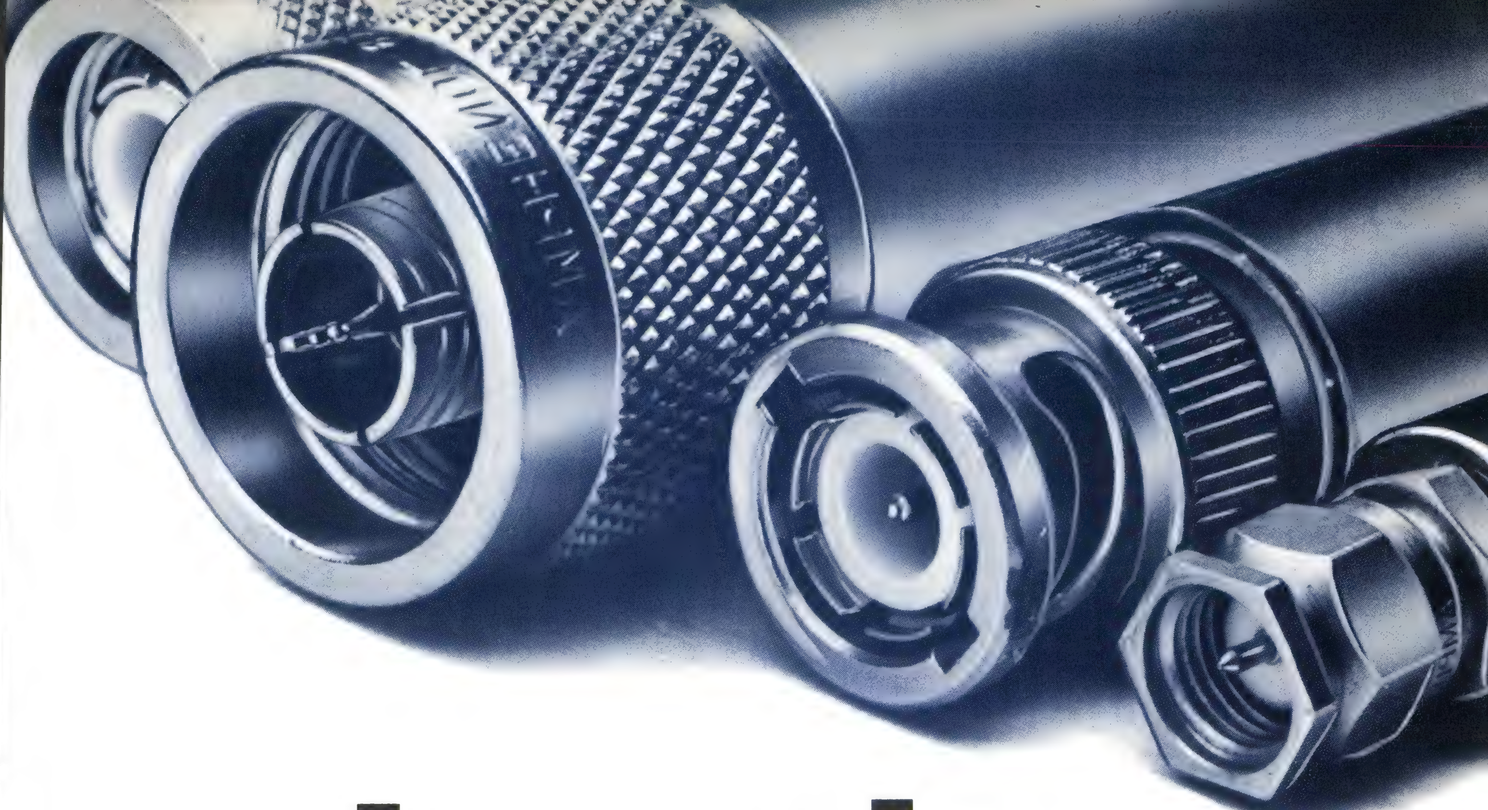

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CIRCLE NO 133

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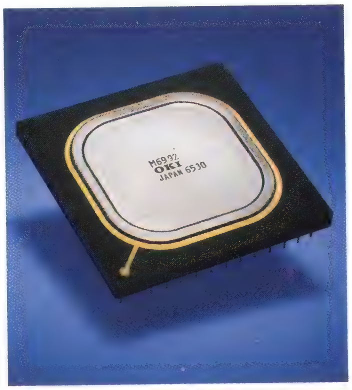

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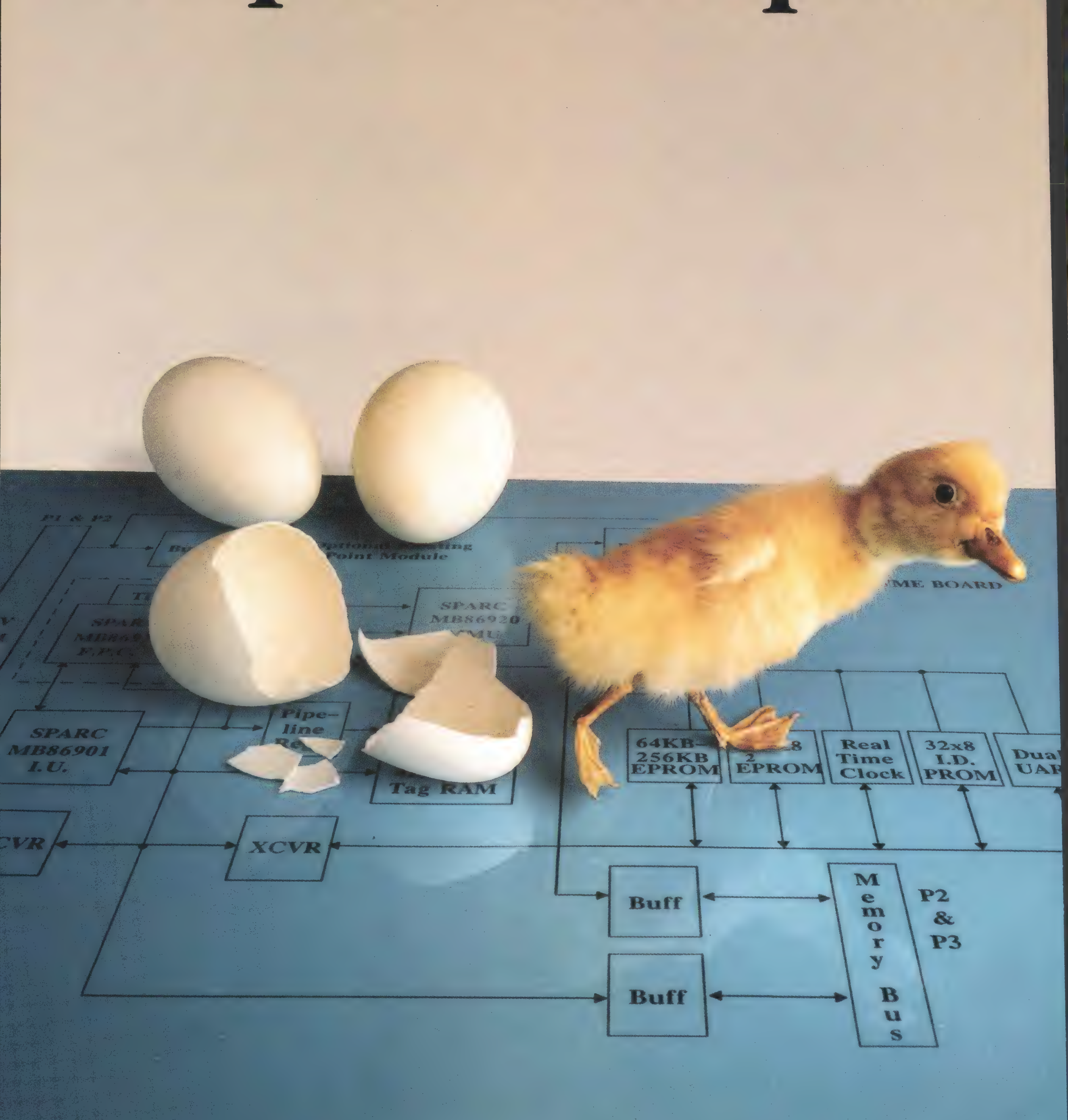
CIRCLE NO 131

Fujitsu's new RISC chip-computer development



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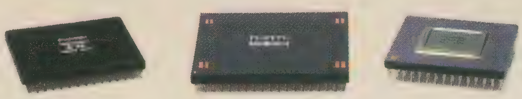

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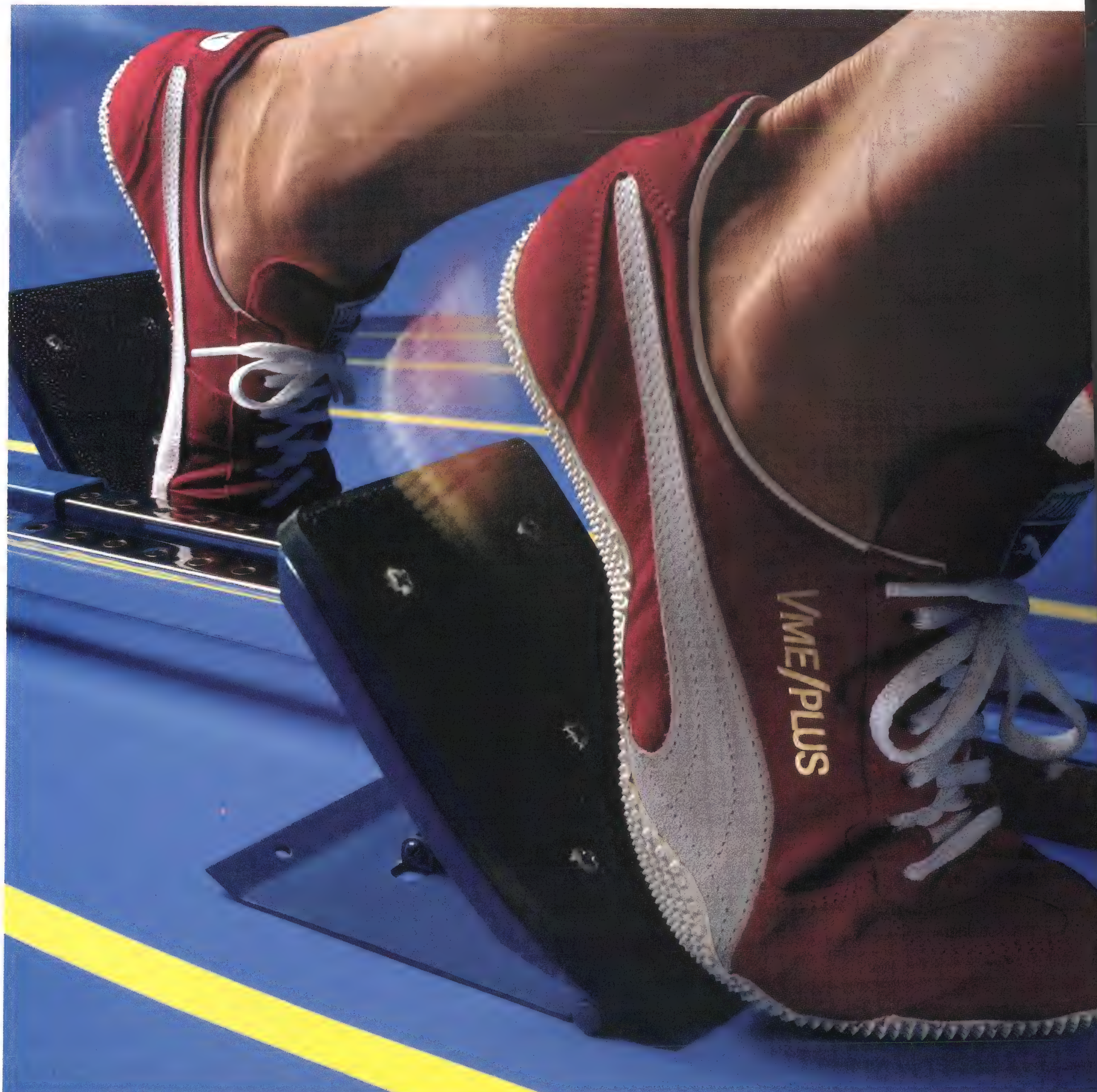

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CIRCLE NO 129

SIGNALS & NOISE

In defense of self-modifying code

With regard to Bob Crispen's remarks (Signals & Noise, EDN, August 18, 1988, pg 32) about my Design Idea "Alterable code enhances instructions" (EDN, May 12, 1988, pg 210), I have three things to say in my defense.

First, the idea of mixing code and data addressing comes from the chip manufacturer. It is published in the manufacturer's data book and is standard practice. The onboard Basic expects it.

Further, the idea of self-modifying code arose from a situation where nothing else would work—an onboard code tracer and a debugger. When resources are as limited as they are on a microcontroller, few solutions can be dismissed out of hand.

For those who think that self-modifying code is used in missiles, etc, and for those whose response to the general idea is nonlinear, I am working on a new product—self-modifying Ada!

Finally, with regard to Bob's remarks about EDN's decision to publish controversial ideas—good for EDN! I'm glad EDN has given space to microprocessor topics. I don't like being the center of controversy, but I love the controversy, and I respect EDN's willingness to be a forum for it.

Noor Singh Khalsa
EG&G Inc
Los Alamos, NM

Self-modifying code isn't the real culprit

I must take exception to Bob Crispen's comments about the perils of self-modifying code. Although self-modifying code can be a source of trouble and should generally be avoided, by itself it is not the cause of software disasters.

Self-modifying code, like GOTOs, will not cause missiles to rain upon our country or airliners to fall out of the sky. Poor design, careless coding, and inadequate testing are the sources of software problems. Wonderful programs have been constructed in terribly unstructured languages, with techniques that would make modern programmers shudder. Unfortunately, programmers often seize upon popular phrases and wave them like banners, rather than focusing on the philosophies behind the words.

Ada, object-oriented programming, and avoiding self-modifying code are not magic solutions to the well-known software crisis. Rather, good engineering and management skills, coupled with the thoughtful application of specific tools and techniques, are fundamental to the design of reliable software systems.

Jack G Ganssle
President
Softaid Inc
Columbia, MD

No protection from missile attack

Bob Crispen need not fear that a self-modifying system is protecting his family from missile attack.

In fact, under the terms of the ABM treaty developed, signed, and defended by a past administration, and supported by the majority of both houses of Congress, the *only* thing legally protecting his family from those missiles, should they come, is the roof of his house.

The Crispen family's best hope is that the proposed Space Shield (SDI) will be put in place, and that one of the 65 to 95% of the missiles it stops will be the one pointed at Decatur, AL. Of course, the very existence of this shield would probably deter the firing of any weapons.

The Crispens' next-best hope is that "the other side" adopts the con-

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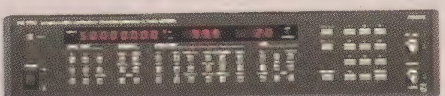

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cept he rightly criticized for their guidance systems.

Gary Fisher
Spectrum Electronics Inc
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Self-modifying code is a reliable tool

In his naive and vitriolic attack on self-modifying code, Bob Crispen has not considered that many single-chip microcontrollers have such a limited instruction set that the programmer is often left with no other viable alternative.

I recently programmed a Hitachi HD63705 microcontroller and a Zilog Z80 microprocessor, using self-modifying-code techniques to implement an enhanced 16-bit pointer and enhanced bit operations, respectively.

As with any memory operation, including stack access, you must take care to ensure the integrity of the data segment. Self-modifying code has been around for quite a while, its techniques are well understood, and it is, in short, a mature, reliable, and versatile tool in the programmer's tool kit.

Jeff Thompson
Design Engineer
BBL Industries Inc
Atlanta, GA

Self-modifying code is fastest and most compact

Self-modifying code is unacceptable, huh? To me, Bob Crispen's letter seems to have more noise than signal.

Let's look at the noise first. Bob says that "Code acts and data is acted upon." To further his point, he expounds: "To confuse the two by executing data or by modifying code as it runs is to commit an error so grave as to destroy the very possibility of software design." Well, I guess Bob hasn't heard about mod-

ern-day assemblers and compilers, which are applications specifically designed to modify code—to create it, in fact!

From my 12 years in the school of software hard knocks, I've come to respect and admire self-modifying code as the fastest, most compact, and most innovative code available. The world's fastest real-time processor, the Harris RTX2000, proves my point. The RTX2000 runs circles around other real-time processors, even when the others are running at their higher clock rates. (The 8051 is not even one of the finalists in this race.) Was the RTX2000 designed with separate code and data spaces? And are engineers afraid to use the RTX2000 in missiles and aircraft because they fear the unknown? On the contrary, Mr Crispen.

The RTX2000 runs Forth, the language that executes data. I'll say it again: Forth, the language that executes data. Countless thousands of software applications in use around the world today run on hundreds of different types of processors, with the sad exception of separated-code-and-data processors like the 8051.

Come on, Bob, let's move out of the college software department and into the real world. (Or maybe that's just it; self-modifying code is hell for hackers to decipher. Is that what's troubling you?) Well, all is not lost. Most Forth systems, including the RTX2000s, come with a professional decompiler built in and ready to use.

Howard Johnson
President
Pistohl Electronic Tool Co
Cupertino, CA

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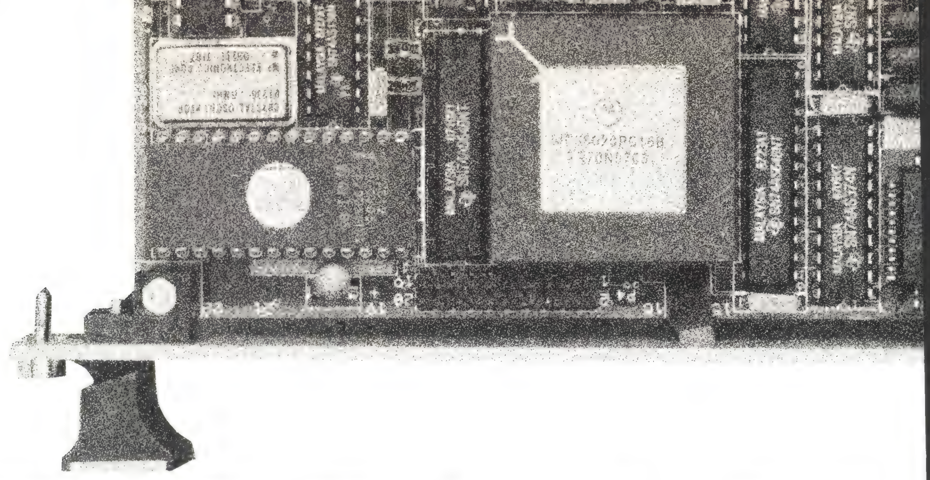

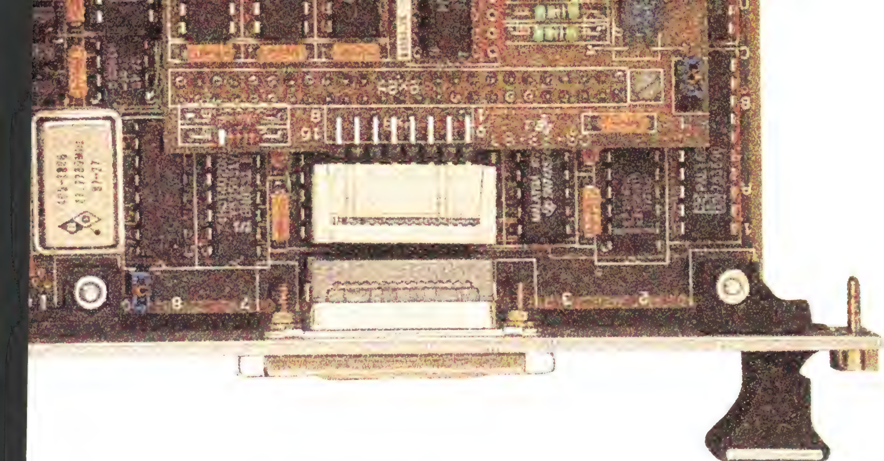

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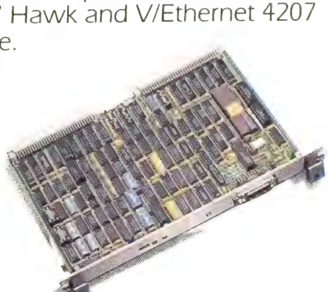

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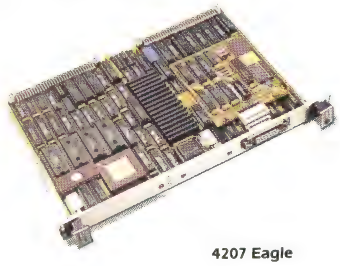

4207 Eagle

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CIRCLE NO 121

CALENDAR

Power Electronic Conference '89, Santa Clara, CA. Bob Mignarri, Conference Management Corp, 200 Connecticut Ave, Norwalk, CT 06854. (203) 852-0500. February 7 to 9.

First International Tape Automated Bonding Symposium, Sunnyvale, CA. Subash Khadpe, Semiconductor Technology Center, Box 38, Neffs, PA 18065. (215) 799-0919. February 13 to 15.

Software Development '89, San Francisco, CA. Miller Freeman Publications, 500 Howard St, San Francisco, CA 94105. (415) 995-2471. February 14 to 17.

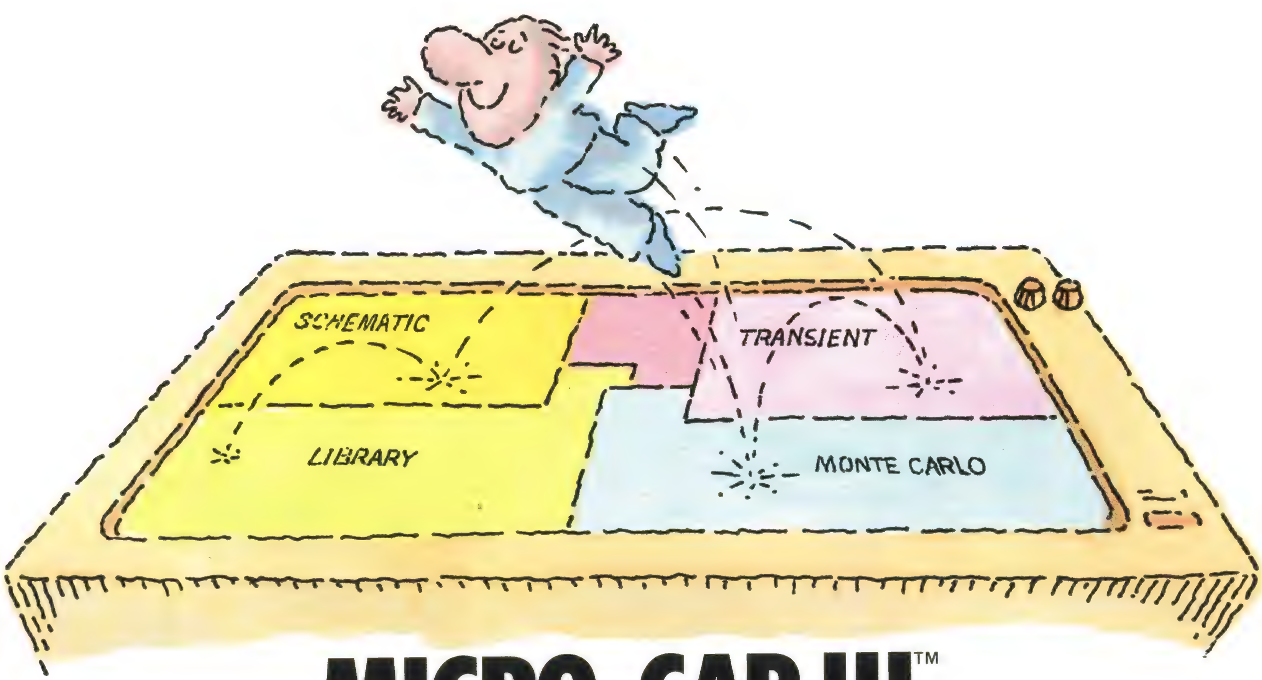
Selling in Japan and the Pacific Rim: New Developments and New Strategies (seminar), Washington, DC. Electronic Industries Association, 1722 Eye St NW, Washington, DC 20006. (202) 457-4930. February 21 to 22.

Power Supply Design Seminar, Tampa, Orlando, and Fort Lauderdale, FL; Huntsville, AL. Unitrode Corp, 580 Pleasant St, Watertown, MA 02172. (617) 926-0404. February 21 to 24.

Semiconductor User and Applications Industry Conference, San Francisco, CA. Dataquest, 1290 Ridder Park Dr, San Jose, CA 95131. (800) 624-3282. February 27 to 28.

Digital Signal Processing, Single-Chip DSP Processors, Development Systems—Theory, Designs and Applications (seminar), Anaheim, CA. Dr Amnon Aliphas, DSP Associates, 18 Peregrine Rd, Newton, MA 02159. (617) 964-3817. February 27 to March 1.

Compcon Spring '89 (34th IEEE Computer Society International Conference), San Francisco, CA. Kenichi Miura, Fujitsu America, 3055 Orchard Dr, San Jose, CA



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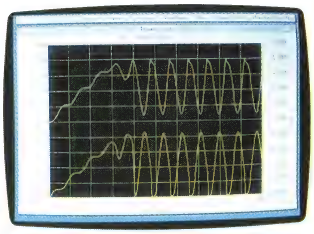
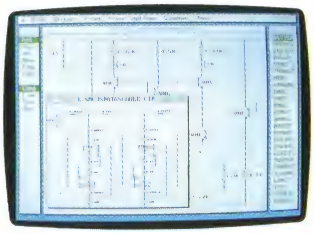
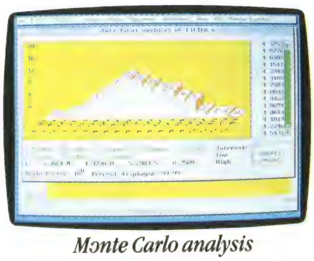


Transient analysis



Schematic editor



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CALENDAR

95134. (408) 432-1300. February 27 to March 3.

Commercially Available Reduced-Instruction-Set Computer Processors (seminar), Anaheim, CA. Dr Amnon Aliphas, DSP Associates, 18 Peregrine Rd, Newton, MA 02159. (617) 964-3817. March 1 to 3.

Systems Engineering for Integrated Hardware/Software Applications (short course), Los Angeles, CA. John Valenti, Integrated Computer Systems, Box 3614, Culver City, CA 90231. (800) 421-8166; in CA, (231) 417-8888. March 7 to 10.

The Executive Forum on Supercomputing, San Jose, CA. Pat Westly, Westly Enterprises, 3697 S Court, Palo Alto, CA 94306. (415) 494-7115. March 9 to 10.

APEC '89 (IEEE Applied Power Electronics Conference and Exposition), Baltimore, MD. Trey Burns, Data General Corp, 4400 Computer Dr, E213, Westboro, MA 01580. (508) 870-9182. March 13 to 17.

C Programming Workshop, Seattle, WA. Specialized Systems Consultants Inc, Box 55549, Seattle, WA 98155. (206) 527-3385. March 13 to 17.

Modern Electronic Packaging (seminar), San Diego, CA. Technology Seminars Inc, Box 487, Lutherville, MD 21093. (301) 269-4102. March 20 to 22.

DCA Forecast to Industry (seminar), Tyson Corner, VA. Janie Herring, AFCEA NOVA Chapter, The BDM Corp, 7915 Jones Branch Dr, McLean, VA 22101. (703) 848-6944. March 27 to 28.

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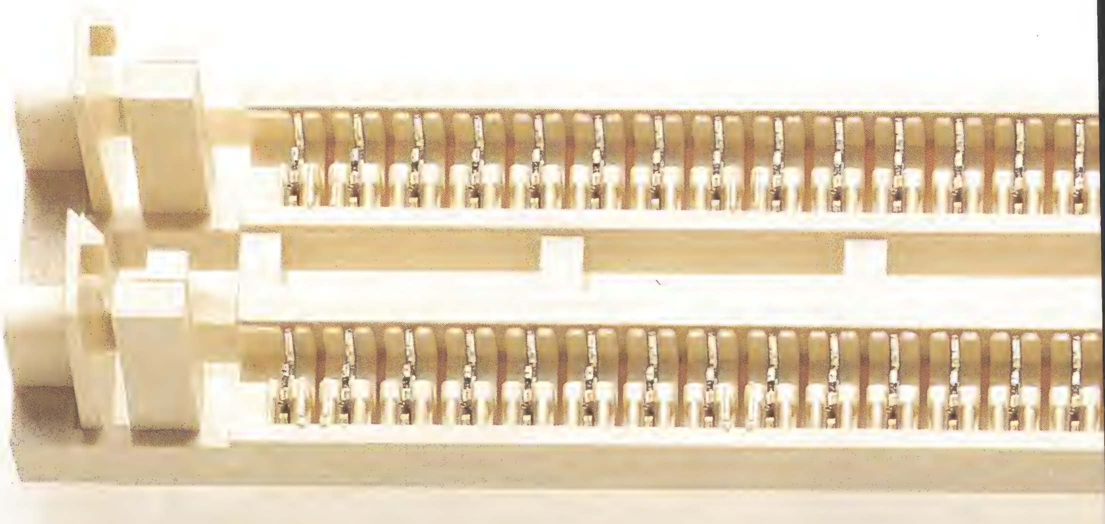
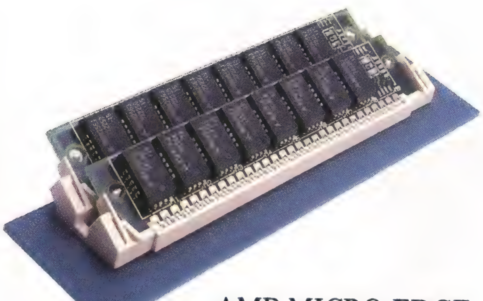


High sec



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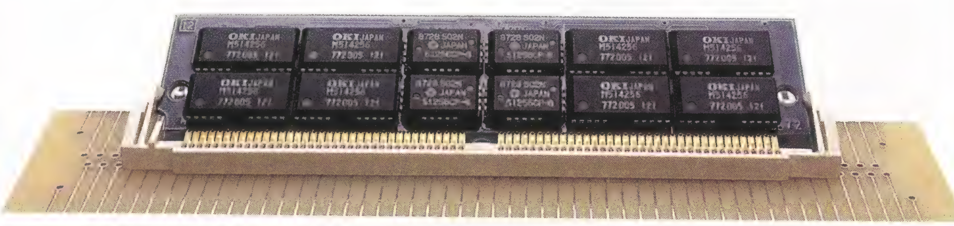

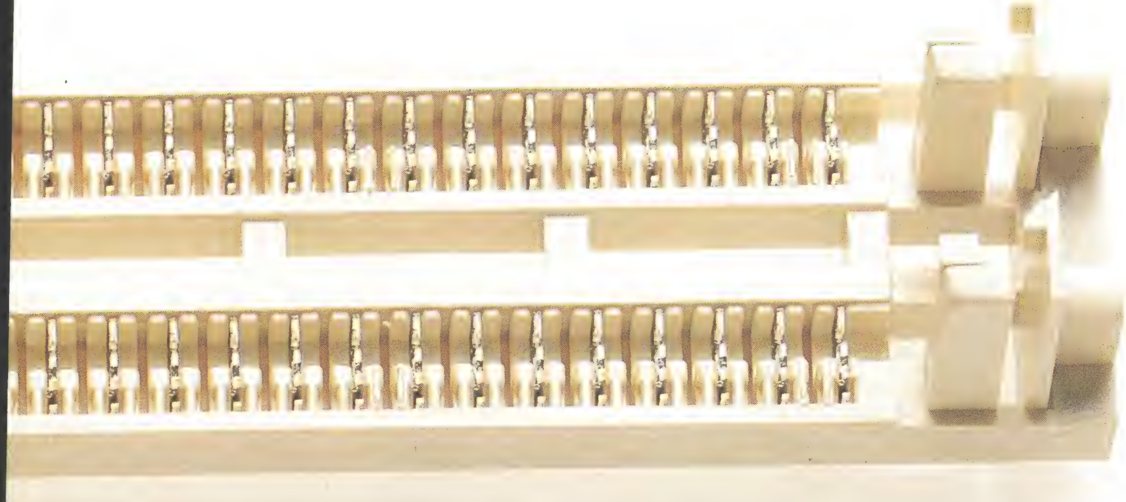

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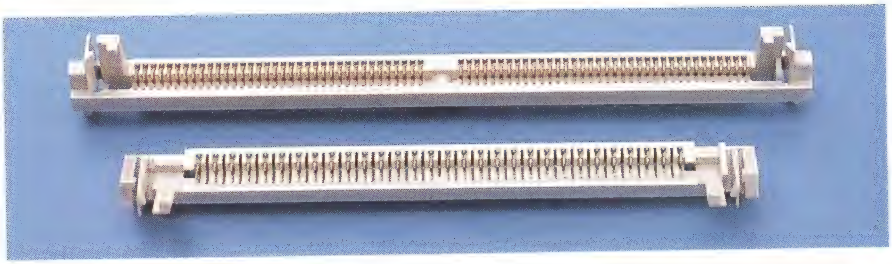

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CIRCLE NO 113

Open the IEEE

When they visited the US last fall, my in-laws, who are Canadian, were amazed by the variety of referendum questions on our local election ballots in Massachusetts. In Canada, there is no law that lets citizens sponsor ballot initiatives by gathering a certain number of signatures. Our Canadian visitors would feel right at home at the IEEE. Its constitution and bylaws have no provisions for member-sponsored changes that members can then vote on. Except for petition candidates, all election questions must arise from the IEEE's Board of Directors. That situation must change.

A professional organization the size of the IEEE must be open to direct initiatives from its members. The IEEE's leaders don't have a monopoly on good ideas for improving and changing the organization. In fact, many of the leaders are so far removed from day-to-day engineering that they have little understanding of their members' needs. For example, although the IEEE says that its membership roster keeps growing, it has no idea where those new members come from. They may be new engineering graduates, professionals who rejoin after absences of several years, or engineers who move into management jobs. If you don't know who your members are and why they join, it's easy to lead them in the wrong direction.

The opportunity for member-sponsored initiatives holds the promise of injecting a dose of reality into the IEEE and the directions it takes. Changing the IEEE's constitution and bylaws to allow for member-sponsored ballot questions won't be as difficult as it might seem. In fact, Keats Pullen, a frequent contributor to our Signals & Noise column, offers specific suggestions. In summary, Keats suggests the following changes:

- 1. Add a section to the constitution so that the bylaws can include new voting rules and regulations. Under those new stipulations, members may change the bylaws by a simple majority vote. Further, changes made by members could be undone only by another vote of the members.
- 2. Add two sections to the bylaws. The first section would establish the right of members to call for a vote on bylaw changes and additions made by the Board of Directors. No doubt the members would let many changes pass without a challenge. But the board's changes wouldn't become effective until members decide whether or not they want to mount a challenge, and then vote on the issue during a regular yearly election. The second section would set up a procedure for individual members to sponsor bylaw amendments. In order to get such a proposal on the next ballot, members would have to obtain the sponsorship of a subsidiary society or gather signatures from members—100 members' signatures should do it.

Because states' laws are often ambiguous when it comes to members' rights in societies such as the IEEE, we recommend abiding by Securities and Exchange Commission regulations, which do not allow board members to overrule changes voted in or out by members.

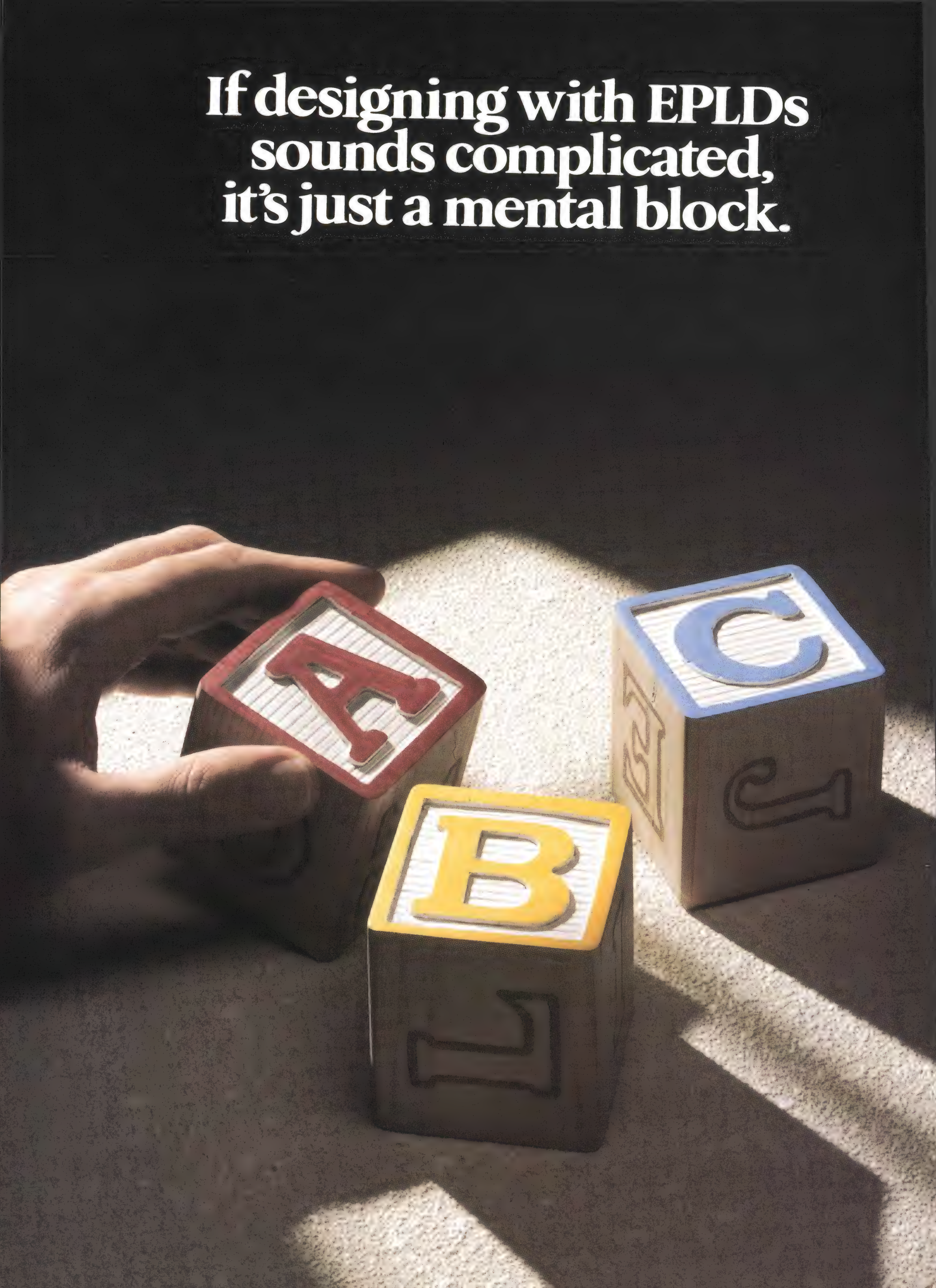
If the IEEE wants to be an open society that's responsive to its members, we can think of no better way than respecting the ability of the members to decide important issues for themselves. It's time to let members approve or disapprove of the Board of Directors' actions and to put their own proposals up for a vote without the board's prior consent.

Jesse H Neal
Editorial Achievement Awards
1987, 1981 (2), 1978 (2),
1977, 1976, 1975

American Society of
Business Press Editors Award
1988, 1983, 1981

Jon Titus

Jon Titus
Editor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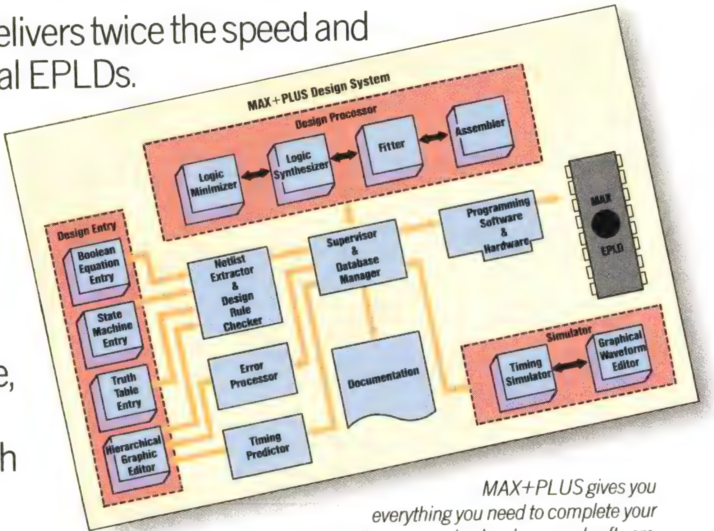

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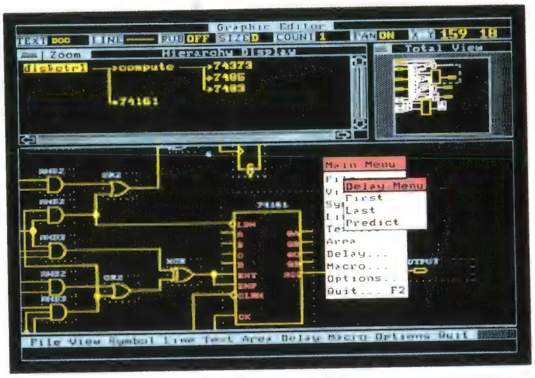

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TRANSPUTER-BASED ADD-IN BOARDS

Software determines board choices

The controversy over Occam vs a more mainstream language, such as C or Fortran, has died down. Now you have to decide whether or not to use a software shell such as an operating system or a programming environment.

Margery Conner,
Regional Editor

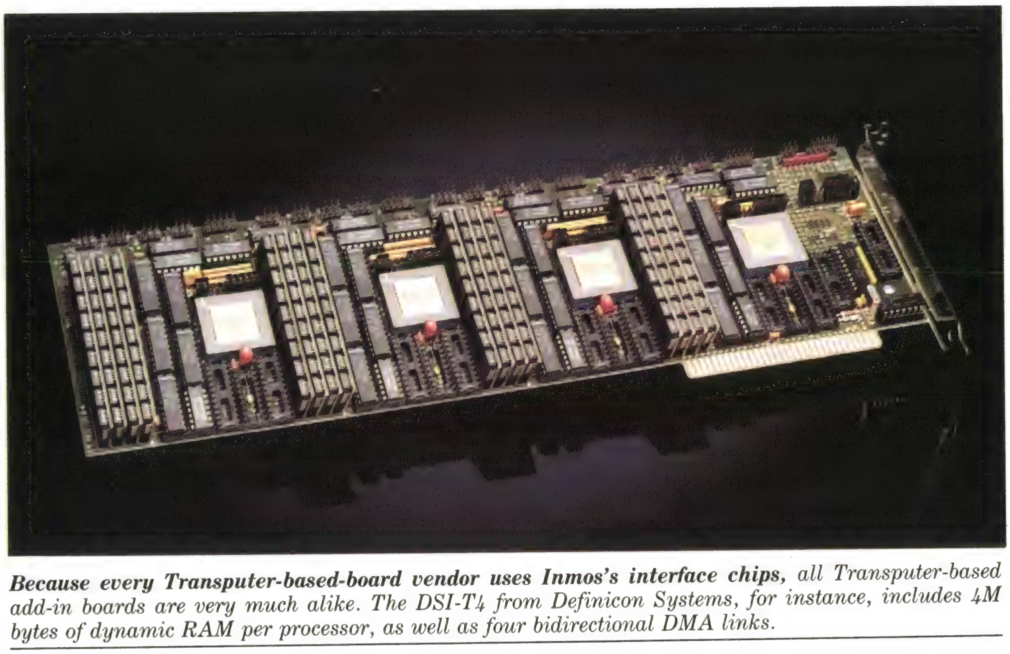
There's a very compelling reason to consider a Transputer-based add-in board: It can make your Sun, VAX, IBM PC, or Apple Macintosh run faster. Unfortunately, programming a Transputer-based parallel-processing board is an art, and an obscure one at that. Thanks to recently introduced software packages, however, the task of programming promises to become easier.

Ultimately, you may find that the software that comes with the board is the major factor in determining which board is the best for your application. The boards themselves are very similar. The basic hardware design of a Transputer-based add-in board is straightforward (**Fig 1**). Typically, a board comes with one Transputer and has sockets for three more. Each Transputer has its own bank of dynamic RAM and a dynamic-RAM controller. Via the board's crossbar switch, you can link the four Transputers in almost any configuration. The crossbar switch also connects the board's Transputers to other Transputers on other boards, allowing topologies (methods of connections) having 32 or more nodes. (A node is a processing element—in this context, a Transputer.)

Three's a charm

You will find three minor areas of difference between boards: the number of Transputers per board, the amount of memory that each Transputer has, and whether or not the board can move data between Transputer-based boards located across the room from each other. Depending on your application, these hardware differences will carry more or less weight.

Table 1 lists the characteristics of sev-



Because every Transputer-based-board vendor uses Inmos's interface chips, *all Transputer-based add-in boards are very much alike. The DSI-T4 from Definicon Systems, for instance, includes 4M bytes of dynamic RAM per processor, as well as four bidirectional DMA links.*

eral representative Transputer-based boards, including the number of Transputers each contains and the basic memory configuration. You'll notice that all of the boards support at least two Transputers. Several of **Table 1**'s manufacturers, however, do also offer boards that contain only a single Transputer. You can use a single-Transputer board to experiment with parallel-processing software without spending too much money.

Whether a Transputer board is capable of moving data between different boards or not depends on whether it has onboard differential line drivers. Transputer-based parallel-processing networks work their fastest when communicating with other Transputers via links (the Transputer's 10M-bps serial-communication channels), as opposed to talking to the host system's processor over the system bus. These links can easily drive Transputers located on the same board, or another board in the same system chassis. If you want to connect other Transputers, however—those plugged into a chassis on another desk across the room, for example—you'll need a board with additional line driver capability.

The Definicon, Computer Systems Architects (CSA), and Paracom boards have differential line drivers that can drive data over distances of 40 ft or more **(Fig 1)**. Keep in mind that if your network of Transputers will fit in one system, you won't need the extra line-driving capability—or the extra cost. In this case, a board such as the Quadputer from Microway is sufficient.

Occam, C, or Fortran?

In the past, the major software decision associated with the Transputer was whether to use Occam, the language that Inmos developed for it, or whether a parallel

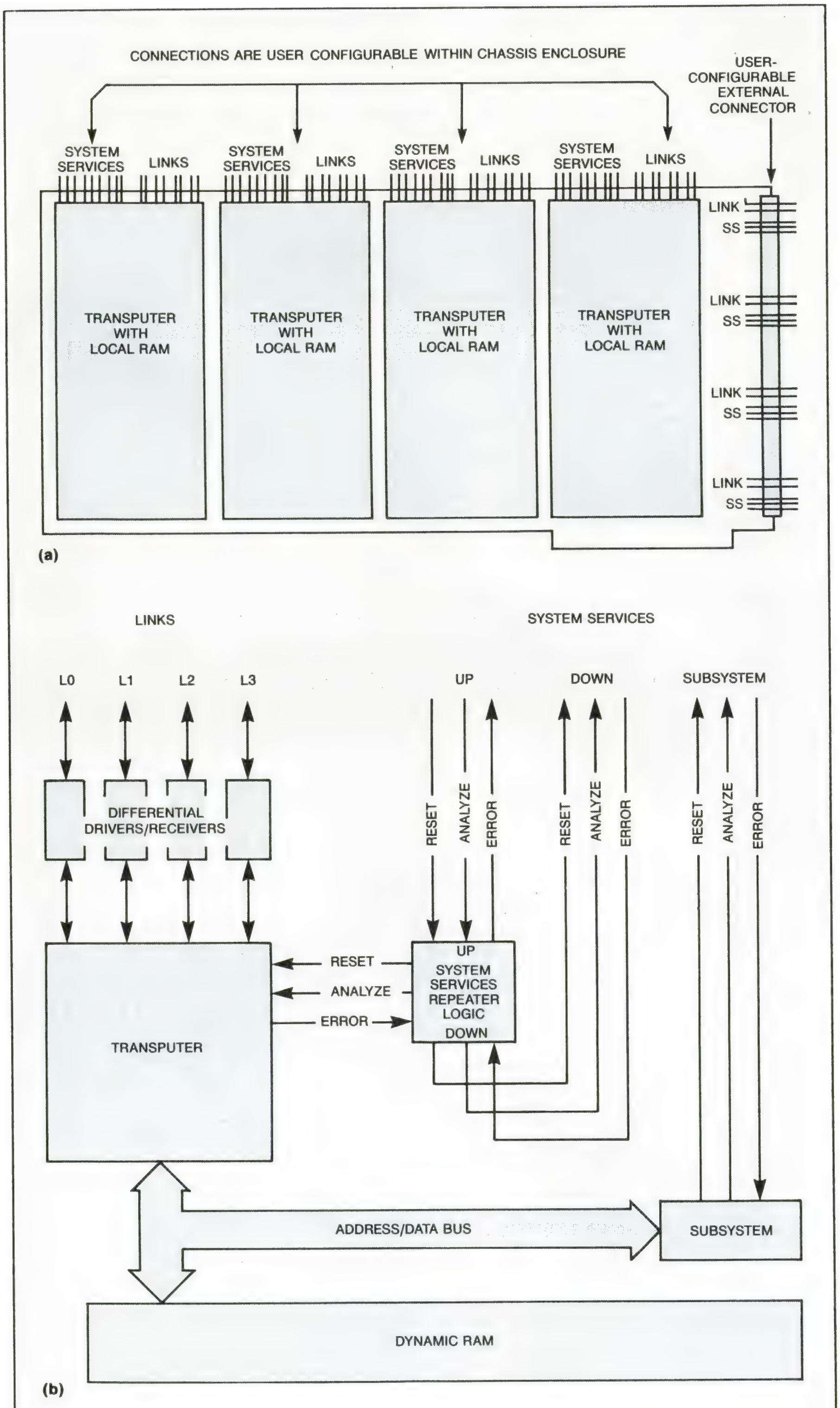


Fig 1—Representative of Transputer-based add-in boards for the PC/XT bus, *the Part.6A board from Computer Systems Architects has external connectors for linking Transputers within the chassis and outside it* ***(a)****. Differential driver/receivers can drive data across a room via link adapters* ***(b)****. The System Services Repeater Logic enables the host computer to broadcast System Services signals over a Transputer network without signal degradation.*

Transputer-based add-in boards

TABLE 1—REPRESENTATIVE TRANSPUTER-BASED ADD-IN BOARDS[1]

MANUFACTURER	BOARD	TRANSPUTERS PER BOARD	BUS	MAX RAM PER TRANSPUTER (M BYTES)	OPERATING SYSTEMS OR PROGRAMMING ENVIRONMENTS	COMPILERS	PRICE	COMMENTS
CAPLIN CYBERNETICS CORP	QT2	2	MICROVAX	2	HELIOS, VMS	FORTRAN, C, PASCAL	3995£	QT4 BOARD WITH 4 TRANSPUTERS, EACH WITH 1M BYTES OF RAM IS ALSO AVAILABLE FOR 5595£.
COMPUTER SYSTEMS ARCHITECTS	PART.6A	4	PC/XT	1	OCCAM PROGRAM DEVELOPMENT SYSTEM[2]	C, FORTRAN	WITH 2 T800s, $8800	LOGICAL INTERFACE TO THE PC/XT BUS IS THROUGH CSA'S DMA-LINK-ADAPTER BOARD, SOLD SEPARATELY; PART.6B WITH 2M BYTES PER TRANSPUTER IS ALSO AVAILABLE.
DEFINICON SYSTEMS INC	DSI-T4	4	PC/XT	4	HELIOS, EXPRESS	C	$7490	BOARD HAS 4 BIDIRECTIONAL DMA LINKS; 2-TRANSPUTER VERSION COSTS $2690.
INMOS CORP	IMS TRAM	1 PER MODULE	PC/XT, VME	8	TRANSPUTER DEVELOPMENT SYSTEM	OCCAM	WITH 1 T414 AND 1M-BYTE RAM, $1807; WITH 1 T800 AND 1M-BYTE RAM, $2191	MODULES PLUG INTO PC/XT OR VME BUS ADAPTER BOARDS, WHICH ACCOMMODATE 10 TRAMs EACH; 10-SITE MOTHER BOARD IS AVAILABLE FOR $1225.
LEVCO	TRANSLINK II	4	APPLE MAC II	4	EXPRESS	C, OCCAM	MOTHER BOARD, $799; T800 MODULE WITH 1M-BYTE RAM, $2199	MOTHER BOARD CAN HOLD 4 MODULES.
MICROWAY INC	QUADPUTER	4	PC/XT	4	OCCAM TOOL SET	C, FORTRAN, OCCAM, PROLOG, PASCAL	WITH 1 T800 AND 1M-BYTE RAM, $1945	NETWORK TOPOLOGY DETERMINED BY PERSONALITY MODULE.
PARACOM INC	VMTM	4	VME (SUN)	1	HELIOS	C, PASCAL, OCCAM, FORTRAN	WITH 4 T414s, $8375; WITH 4 T800s, $9775	
	MTM-PC	4	PC/XT	1	HELIOS	C, PASCAL, OCCAM, FORTRAN	WITH 4 T414s, $7795; WITH 4 T800s, $9195	
	MTM-MAC	2	APPLE MAC II	2	HELIOS	C, PASCAL, OCCAM, FORTRAN	WITH 2 T414s, $5485; WITH 2 T800s, $6185	
TOPOLOGIX INC	TOPOLOGY 1000	4	VME (SUN)	16	LINDA, LOGIXOS	C, FORTRAN, LISP	$2400	THE LINDA PARALLEL-PROCESSING ENVIRONMENT RUNS UNDER TOPOLOGY'S PROPRIETARY LOGIXOS, A UNIX-LIKE OPERATING SYSTEM.

NOTES:
1. ALL BOARDS ARE AVAILABLE WITH EITHER THE T414 OR T800 VERSION OF INMOS'S TRANSPUTER. (THE T800 IS SOFTWARE AND HARDWARE COMPATIBLE WITH THE T414, BUT HAS AN ON-CHIP FLOATING-POINT UNIT.)
2. SAME AS INMOS'S TRANSPUTER DEVELOPMENT SYSTEM.

version of a more mainstream language, such as C or Fortran, was more appropriate. As you might expect, programmers split into two camps: zealots who made the investment in time to learn Occam, and those who opted for C or Fortran because they were more familiar with them.

Nowadays, you have a different decision to make regarding Transputer software: To use an operating system or a programming environment. An operating system takes care of routine housekeeping chores such as file handling and peripheral-hardware control; a programming environment dispenses with these capabilities and instead uses a host operating system that fulfills these functions. Basically, a programming environment is a stripped-down version of an operating system; like an operating system, it provides the capability to perform the three tasks necessary for parallel-processing programming: data distribution, load balancing, and message passing.

Before you begin weighing the pros and cons of an operating system vs a programming environment, Glen Lowry, marketing director at CSA, suggests that you first determine whether you really *need* the software shell of an operating system or environment.

According to Lowry, there are two basic kinds of parallel-processing-board users. The first is experienced in parallel processing and is using a Transputer because of its speed advantage. For this person, going through an operating system or a programming environment would just add another software layer and a corresponding loss in speed.

In contrast, he says, the second type of Transputer-based-board user is a novice, unsure that parallel processing is right for his or her particular application, but eager to experiment with an add-in board. For this user, the convenience of an operating system, with its input/output and file-handling capabilities already thoroughly debugged, is a tremendous time-saver.

You might want a debugger

Even if you decide to dispense with a software shell—operating system or programming environment—Lowry suggests that you'll still benefit from a debugging tool like Parasoft's (Mission Viejo, CA) Parallel Debugger. With the $295 Debugger, you can trace your parallel-processing program through each step, checking memory and registers on each node. Once you've resolved all the problems, you can pull the Debugger out and still have your minimum software configuration.

John Poplett, software director for Definicon Systems, agrees that operating systems and programming environments save learning time, but feels that they are useful for *anyone* doing parallel programming. He points out that the operating-system and programming-environment developers are among the few programmers experienced in the new field of parallel processing. According to Poplett, the chances are slim that a user would be able to significantly improve on the software speed that the developers have achieved.

At present, you have a choice of three software shells: Helios, which is an operating system, and Express and Linda, both of which are programming environments. Distributed Software Limited (Bristol, UK) sells Helios; it is available bundled with boards from Caplin Cybernetics, Definicon, and Paracom. Express's vendor is Parasoft; it comes on Definicon, Microway, Levco, and CSA boards. Linda is a university project developed at Yale and is only available on Topologix boards.

Helios offers the capability to perform data distribution, load balancing, and message passing. It also includes all of the functions you'd expect of an operating system such as disk management, peripheral control, and I/O servers for the

Graphics displays capitalize on parallel processing

The power of parallel processing is ideal for graphics-display applications. However, because the boards in the accompanying article and **Table 1** are all general-purpose add-in boards, they don't have graphics-display hardware; rather, they drive the graphics display through the system graphics controller. Unfortunately, using the host's graphics-display hardware adds a delay to the time it takes for the graphics to appear on the screen.

If you have an application that can't abide by this time penalty, you can overcome this restriction by using a specialized Transputer-based add-in board—the DSI-TG2 from Definicon. The board contains two T414 Transputers, each with 1M bytes of dynamic RAM, a frame buffer memory, three video DACs, interface circuitry, and CRT control electronics. You can link the board to other nongraphic Transputer boards to form various topologies. Of course, you have to pay extra for the graphics-control electronics; the DSI-TG2 costs $2495.

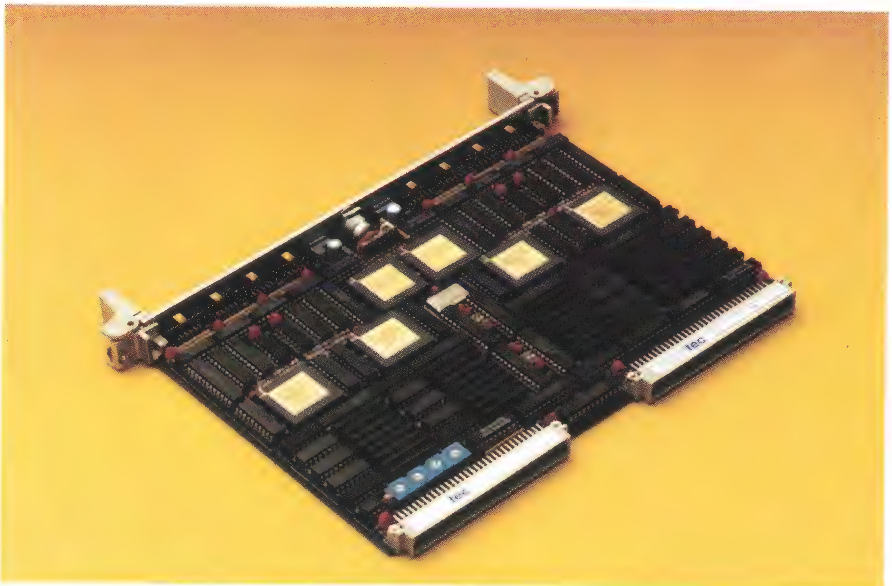
screen, keyboard, and mouse. Moreover, it also supports something you might not expect—a multitasking, time-sliced environment.

If your intent in using parallel processing is to accelerate a computation-intensive algorithm, a multitasking operating system probably won't suit your requirements. A programming environment is better suited to tasks such as matrix multiplication.

Express and Linda rely on a host operating system such as MS-DOS, Unix, or that of the Apple Mac II to provide the usual operating system functions. A programming environment consists of a library of subroutines, supporting both C and Fortran, that handles load distribution, data distribution, and message passing between the various processes.

A process refers to an individual job that some processor in the network must perform. There is no requirement that each process have its own dedicated processor; because multiple processes can (and probably will) run on one Transputer, you can develop your software on a system with just one Transputer. The parallel-processing speed will increase—along with the cost—as you approach one process per Transputer.

Load distribution is how the different processes in a parallel program are apportioned among the Transputers. This capability is important because you may want to change the number of Transputers in your system or their topology. Using a command statement, for example, you can configure Express for your hardware when you first start up, and Express will then automatically perform the load distribution. This capability means that your software is independent of the number of Transputers available. You can develop the software on a system with one Transputer,



A Transputer-based add-in board for the VME Bus, *the VMTM from Paracom runs under the Helios parallel-processor operating system. The board costs $8375.*

and then move it to a system with, say, 16 Transputers, and achieve a speed improvement without having to rewrite your software.

Data distribution is similar to load distribution. Express and Linda ensure that the data that each process needs is available to each node.

Message passing is how each process shares data with other processes working on the same problem. The hardware connection between the Transputers is via the Transputer's four links. Express and Linda both have a series of commands that allow you to control the data that travels over the links and to what process it goes to.

Task is still formidable

As you can imagine, though the programming environment handles many of the system's housekeeping chores, developing a parallel program is still a formidable task. Larry Lesser, president of Parasoft, says that the most important thing for the novice parallel programmer to do is to simplify the programming task as much as possible.

Parallel programming is not only very difficult, but few are trained in it. Lesser suggests that the easiest way a novice can develop a program is to take one that already runs on a sequential machine—albeit too slowly—and parallelize the computationally intensive parts. With Express, for example, you can first debug the algorithms that you are parallelizing for vector multiplication of a matrix and make sure that the algorithm's software works on one node. You can then address the complicated part of determining how many Transputers you need or what the optimum topology is.

Express assumes that your system will have distributed memory—that is, that each node will have its own private RAM that no other node can access without permission. Although it's possible to use a shared-memory architecture with Express, it's the programmer's responsibility to keep track of memory. For example, you can get in trouble with a shared-memory architecture when one Transputer contaminates memory that another Transputer is working

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on. Shared memory can be a dangerous architecture for a Transputer-based system; the Transputer doesn't have a memory-protection scheme such as you find on a processor meant for multitasking, like the 80386.

What's "tuple space"?

Linda does support a version of a shared-memory architecture. The programming environment incorporates commands that allow you to treat portions of shared memory as "tuple space." Tuples are combinations of typed fields and are independent of memory addresses; they use associative memory lookup. Linda supplies the commands that allow you to read, write, and manipulate the data in these fields. To find a particular tuple, you search for it using some combination of the data stored in the key.

In trying to decide between the Express and Linda programming environments, your choice may very well boil down to the memory usage in the programming model that best suits your application. In choosing between an operating system and a programming environment, you'll have to base your decision on broader criterion. Helios is probably the best software shell for a process-control application, whereas Linda or Express are better suited to performing matrix multiplication.

Regardless of which operating system or programming environment you choose, you should be aware of the deadlock phenomenon. Deadlock occurs when all the nodes in a network try to pass a message simultaneously: No one can get through and all hang up. Although Helios, Express, and Linda can support any topology, they don't guarantee that all the topologies they support are safe from deadlocks. For example, Express is only immune from deadlock for three basic topologies: hypercube, 2-D mesh (taurus), and tree. You won't be happy with an esoteric topology that offers a minor speed advantage over one of the standard topologies if your system succumbs to deadlock. EDN

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Article Interest Quotient
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For more information . . .

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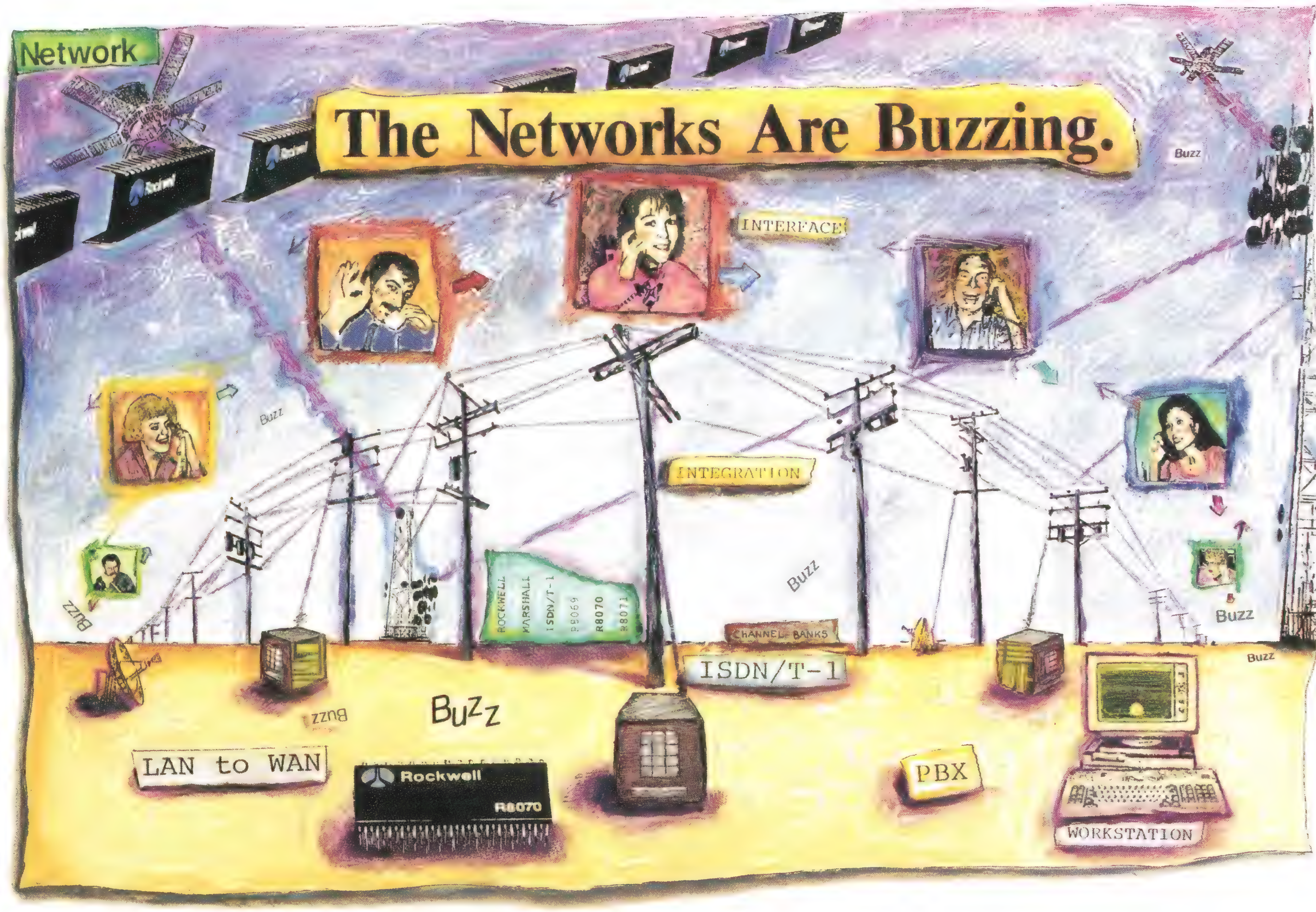

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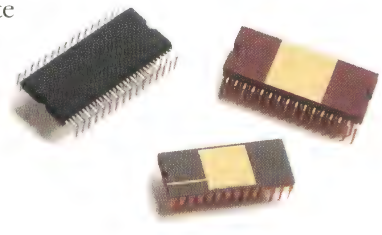

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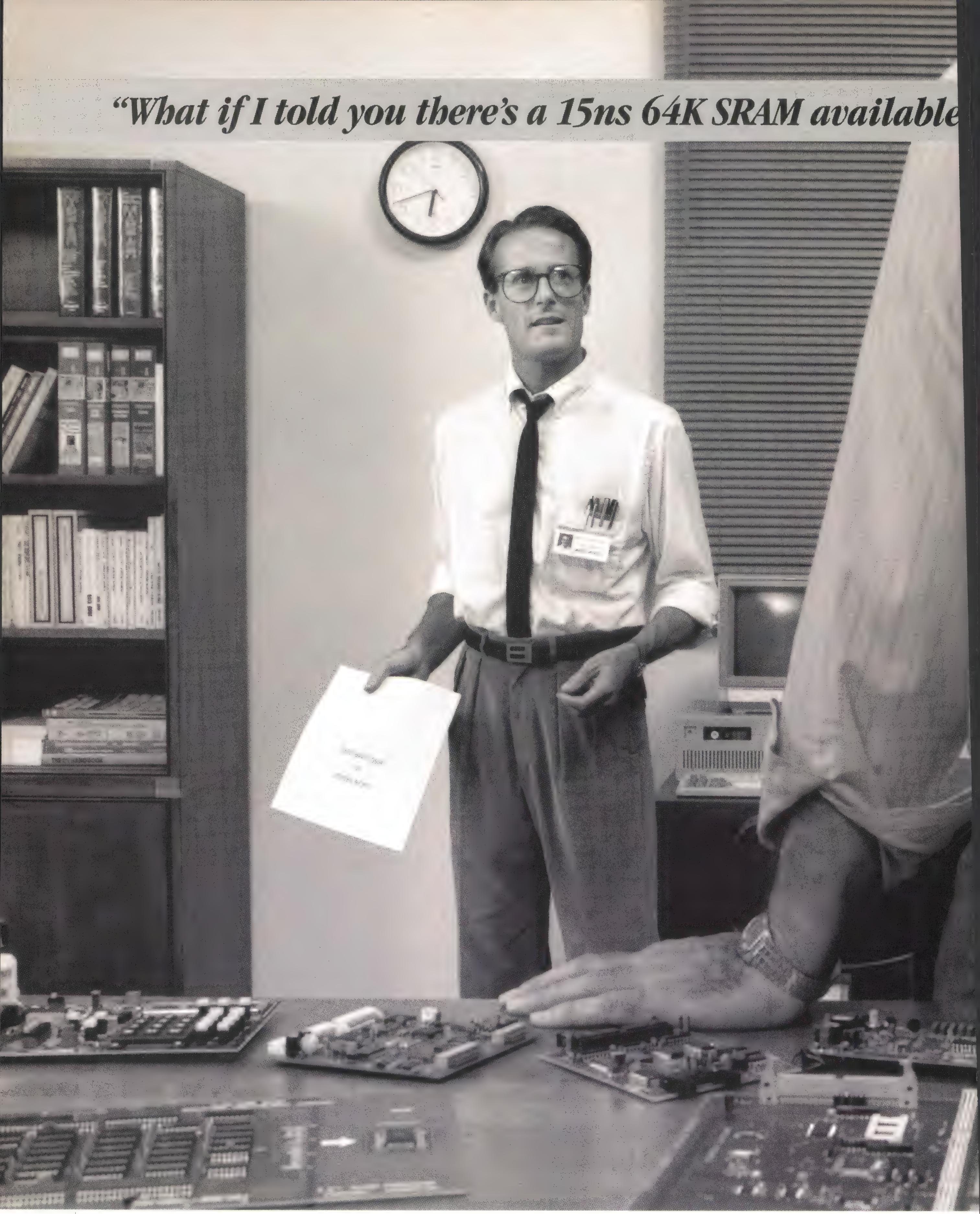
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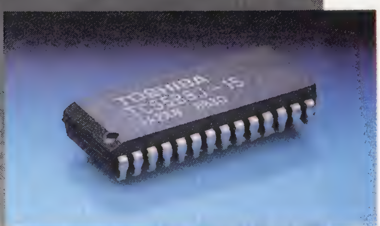

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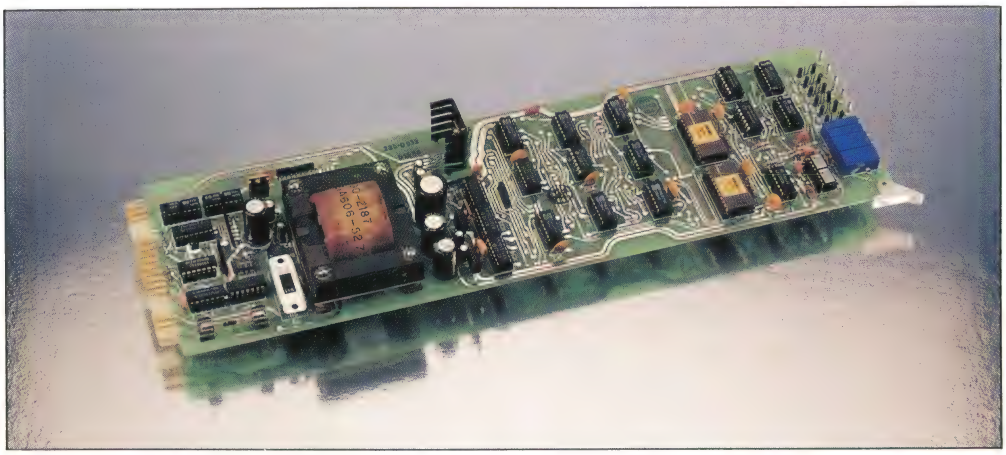
Although the market for digitally programmable dc sources and loads is much smaller than that for fixed-output dc supplies, and both the performance requirements and the product complexity are very high, the array of digitally programmable dc supplies and loads that are available off the shelf is rather large (**Table 1**). In some of the products, programmability is an integral feature; in others, it's optional. In still others, vendors create semicustom digitally programmable supplies and programmable-supply systems. They do so by coupling separately packaged programmers to standard supplies with outputs that are adjustable over a wide range. At least half a dozen vendors offer products that fit one or more of these descriptions.

Incidentally, many of these products use linear regulation circuits instead of, or in addition to, the switching regulators that have become so popular in the broader power-supply market during the last decade. Vendors who continue to employ the older, linear, technology cite several reasons for using it in this relatively new class of products (see **box**, "Is programmable power the last bastion for linears?").

Programmable supplies are complex

Designing your own digitally programmable supply might seem a simple enough task at the outset. The task is more demanding than you might expect, however, because the capabilities required of digitally programmable supplies can be quite complex. Probably the



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Digitally programmable supplies

most complex set of requirements is that for the "4-quadrant" supply. Four-quadrant supplies are sometimes called operational power supplies (because of their relationship to operational amplifiers). Electronic loads as well as most digitally programmable power supplies, such as those used to power burn-in racks, possess only a portion of the capability of 4-quadrant supplies.

A 4-quadrant supply must produce both positive and negative voltages; for either polarity of output voltage it must supply (source) or absorb (sink) current. Furthermore, a 4-quadrant supply must usually make smooth transitions

TABLE 1—REPRESENTATIVE DIGITALLY PROGRAMMABLE DC POWER SUPPLIES, PROGRAMMERS, AND DIGITALLY PROGRAMMABLE ELECTRONIC LOADS

VENDOR	MODEL	DESCRIPTION	MAX POWER (W)	NOISE (mV RMS P-P) (BANDWIDTH IN MHz)	US PRICE[1]
ELECTRONIC MEASUREMENTS	BOS/S SERIES	4-QUADRANT OPERATIONAL SUPPLIES. 20 TO 200V MODELS. ALL ARE 5¼ IN. HIGH. IEEE-488 AND RS-232C INTERFACES OPTIONAL.	100, 200, 400	3/NS (NS)	\$1095 TO \$1995
	EMTL-488	PROGRAMMER FOR MOST OF VENDOR'S SUPPLIES. EIGHT 1-CHANNEL UNITS MOUNT IN RACK ADAPTER. 3-CHANNEL UNIT IS FULL WIDTH. 12-BIT RESOLUTION. ACTS AS TALKER OR LISTENER.	NA	NA	\$645 TO \$1895
HEWLETT-PACKARD	6621A-24A 6627A	1-, 2-, AND 4-OUTPUT SUPPLIES; 7 TO 50V MAX.	40 AND 80	0.5/3 (10/20)	\$3400 TO \$4400[2]
	6632A-34A	SINGLE-OUTPUT SUPPLIES; 20, 50, AND 100V MAX.	100	0.5/3 (10)	\$1600[2]
	6030A-33A 6038A	SINGLE-OUTPUT SUPPLIES; 20, 60, AND 200V MAX.	200 AND 1000	3 TO 22/30 TO 50 (NS)	\$2575 TO \$3400[2]
	6050A/60A 60501A 60502A	PROGRAMMABLE ELECTRONIC LOADS. 6060A: 1 INPUT; 6050A: 1 TO 6 INPUTS. 60501A/02A: 150/300W MODULES FOR 6050A. MAX VOLTAGE: 60V	6060A: 300 6050A: 1800	4 TO 6/NS (10)	6050A & 60A \$1800 & \$1995; MODULES \$1250 & \$1550[2]
KEPCO	BOP SERIES	4-QUADRANT OPERATIONAL SUPPLIES. ±20V TO 1 kV MODELS. 5¼ IN. HIGH (TO 200V); 7 IN. (500V AND 1 kV). IEEE-488 INTERFACE OPTIONAL.	100 TO 400 (TO 200V); 40 (500V AND 1 kV)	3/30 (10)[3]	
	SN 488, SNR 488	PROGRAMMERS FOR THE VENDOR'S SUPPLIES. SN IS ¼ RACK WIDTH; SNR CAGES HOLD 4 & 8 CARDS, 1 PER SUPPLY. BINARY AND BCD VERSIONS ARE AVAILABLE.	NA	NA	SN, FROM \$695; SNR, FROM \$579; CARD, \$856
	ATE SERIES	FAST-PROGRAMMING, LINEAR, VOLTAGE/CURRENT SUPPLIES ¼ TO FULL RACK WIDTH. 6 TO 150V.	50, 100, 250, 500, 1000	0.3/3 MAX (10)	\$847 TO \$2807
LAMBDA	LT-870 SERIES	FULL-RACK-WIDTH SUPPLIES WITH INTERNAL IEEE-488 INTERFACE. EFFICIENCY IS >78%. MAX OUTPUTS ARE 7.5, 18, 36, AND 60V.	4200 AT 40°C	20/NS (NS)	\$4500
	LOWER-COST IEEE-488 SYSTEM	CUSTOM-CONFIGURED SYSTEMS BUILT FROM STANDARD UNITS. 1 TO 6 SUPPLIES. OPTIONAL CONFIDENCE-CHECK FEATURE.	DEPENDS ON SUPPLY SELECTED	DEPENDS ON SUPPLY SELECTED	FROM ABOUT \$2800
	MATEPLUS SYSTEM TALK-LISTEN SYSTEM	CUSTOM-CONFIGURED SYSTEMS BUILT FROM STANDARD UNITS. AS MANY AS 31 SUPPLIES. SUPPLIES IMPLEMENT SUPERSET OF MATE REQUIREMENTS. SELF-TEST IS STANDARD. SUPPLIES MOUNT IN ONE OR MORE FULL-RACK DRAWERS.	DEPENDS ON SUPPLY SELECTED	DEPENDS ON SUPPLY SELECTED	DEPENDS ON CONFIGURATION. 6 TO 8 WEEKS DELIVERY.
ROHDE & SCHWARZ	NGPS	DUAL-RANGE BIPOLAR SUPPLY. 16-BIT RESOLUTION ON LOW RANGE.	5	0.5/NS (1) LOW RANGE	\$4490
	NGPU SERIES	FAST-RESPONDING SUPPLIES; 0 TO 70V OUTPUT. 10A MAX AND 20A MAX UNITS.	175 AND 350	1.5/NS (NS)	FROM \$3660
	NGPV SERIES	FULL-RACK-WIDTH SUPPLIES ARE AVAILABLE WITH & WITHOUT PANEL CONTROLS.	80 TO 200	0.2 TO 0.9/NS (NS)	FROM \$2160
	NGPE	HIGH-EFFICIENCY SUPPLY. 0 TO 40V, 40A AT 20V. MOUNTS IN 7-IN. SPACE IN RETMA RACK	400	2/20 (NS)	\$3550
SORENSEN	HPD SERIES	¼-RACK WIDTH SUPPLIES ARE 0 TO 15, 30, 60V. IEEE-488 INTERFACE IS OPTIONAL.	300	5/50 (NS)	\$1195; IEEE-488 OPTION, \$450
TRANSISTOR DEVICES	TD12 SERIES	SOURCES AND LOADS. SOURCES AND LOADS ARE RATED FOR 10, 20, 100, AND 200V LOADS ARE ALSO RATED FOR 50, 100, AND 150A. SIZE IS EITHER HALF OR FULL RACK WIDTH, DEPENDING ON RATING. 5¼ IN. HIGH. PROGRAMMER IS FULL RACK WIDTH, 1¾ IN. HIGH. CONTROLS 1 TO 12 SOURCES/LOADS.	SOURCES: 600 (HALF RACK), 1500 (FULL RACK). LOADS: 400 (HALF RACK), 1200 (FULL RACK)	1/10 (20)	SOURCES AND LOADS, \$2100 TO \$4000; PROGRAMMER \$4000

NOTES:
1. BASE PRICE. IN SOME CASES IEEE-488 INTERFACE IS ADDITIONAL.
2. IEEE-488 INTERFACE IS INCLUDED IN STANDARD UNIT.
3. ON UNITS WITH MAX OUTPUT VOLTAGE OF 100V OR LESS.
NS=NOT SPECIFIED
NA=NOT APPLICABLE

from behaving as a voltage source to acting as a current source. And when acting as a current source, a 4-quadrant supply must produce a programmable current. This combination of operating modes enables many 4-quadrant supplies to act as voltage sources with programmable current limiting, or to act as current sources with programmable voltage-clamping levels.

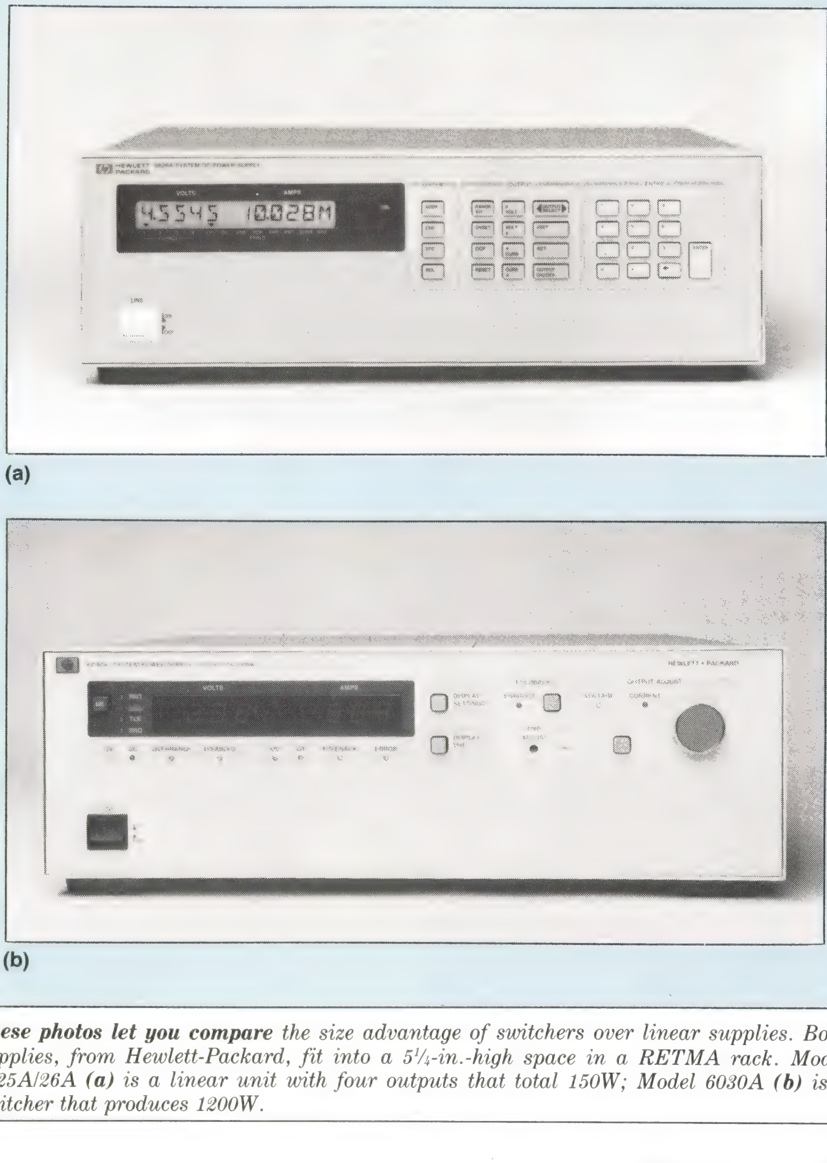
To these requirements, you can often add a number of others. For example, a 4-quadrant supply should have high accuracy (or at least high precision—sometimes at the 16-bit level or greater). It should also provide rapid response without overshoot. Even though most programmable supplies permit remote output sensing, which can make it impossible to predict feedback-loop dynamics, system designers often demand that supply outputs settle within 100 ppm of full scale or less in tens of microseconds. In addition, to ensure rapid response, many programmable supplies omit the large output capacitors common in fixed-output supplies. The absence of output capacitors can further complicate feedback-loop stabilization.

Four-quadrant supplies also require high output power—sometimes hundreds of watts. High reliability and fail-safe operation is also important. Above all, if a supply fails, it shouldn't damage the unit under test to which it has been supplying power.

Finally, the supply must have isolation between analog and digital grounds (and between both grounds and the system chassis), and it must have low noise (sometimes in the microvolt range). Taken as a whole, this set of requirements presents a formidable technical challenge to designers of programmable power sources.

Many of the products that lack the generality of 4-quadrant supplies do, however, offer performance that exceeds that of 4-quadrant units, albeit only in specific areas. For example, a supply that's used to power a burn-in rack normally operates in only one quadrant. That is, it can produce an output voltage of only one polarity, and when supplying a positive voltage, it can't absorb current. Furthermore, its response speed need not be as high as that of an operational supply. On the other hand, such burn-in supplies usually can deliver several times the power that's available from the largest operational supply, and they do so with much higher efficiency.

But besides the requirements already listed, which, for the most part, affect the analog design of a supply, there are additional requirements that govern the digital portion of the design. Except in specialized applications, system designers who use programmable power sources demand simplicity of interfacing and programming. Such requirements usually imply that the hardware interface must conform to an industry standard, such as IEEE-488 (European vendors refer



(a) (b)

These photos let you compare *the size advantage of switchers over linear supplies. Both supplies, from Hewlett-Packard, fit into a 5¼-in.-high space in a RETMA rack. Model 6625A/26A **(a)** is a linear unit with four outputs that total 150W; Model 6030A **(b)** is a switcher that produces 1200W.*

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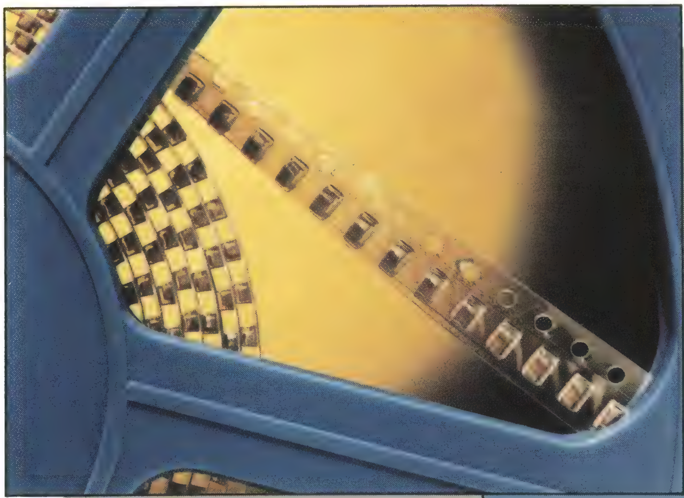

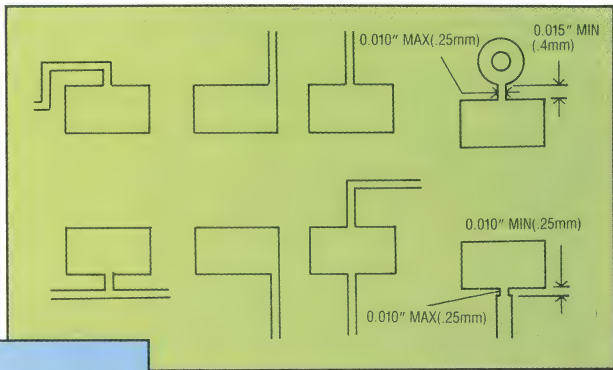

Figure 2
Design Techniques That Work.

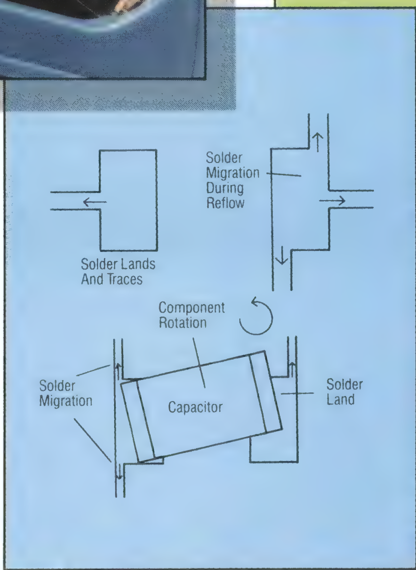

Figure 1
Designs Techniques To Avoid

Zero Defect Design In Surface Mount Applications

Zero defect soldering can be achieved in SMT, but it is essential that the PC board be correctly designed for manufacturability.

Before a design even gets into production, it must have the following:
1. Proper solder fillets 2. Process-tested pad designs 3. Correctly designed trace/pad interaction
4. Proper solder mask 5. Proper component orientation 6. Proper tooling hole location 7. Testability 8. Uniform metalization 9. Cross-hatched power and ground planes 10. Components isolated from high stress areas 11. Pre-routing of corner areas for depaneling.

There is a simple test to see if a design is manufacturable. First, screen solder paste on the pads with a stencil. Then, reflow the board without the components. This will allow close scrutiny of traces and pads for any problem locations. High yield demands that a board must have uniform solder on the pads after reflow to avoid rework.

Excess solder is a major cause of chip component defects. Great globs of solder are easy to inspect but do nothing for strength. They also increase handling damage and reduce yields through drawbridging and shorting.

Solder fillet shape and size are ultimately determined by pad design and their interaction. Therefore, use only pad designs which have been proven in tens of millions of connections. The best source for pad design information is either other users or experienced vendors such as AVX. Once pad designs are chosen, test them in your manufacturing process. Then, thermal cycle and environmentally test the assembly. There is interaction between pads through the connecting traces. Use common sense in the layout and follow the simple rules illustrated in the do's and don'ts of Figures 1 and 2.

For more information on achieving zero defect in surface mounting ceramic capacitors, please return coupon below to AVX to obtain a copy of the technical paper "Surface Mount Zero Defect Design".

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to IEEE-488 as IEC-625), and that the command set must conform either to a de facto or an established standard. One established standard is CIIL (Control-Interface Intermediate Language), which is widely used in military ATE systems, especially those that conform to the Air Force's MATE (Modular Automatic Test Equipment) guidelines.

To a supply that conforms to MATE and CIIL requirements, the IEEE-488 bus is much more than a means of receiving commands that determine a new output voltage. Such supplies can act as "talkers" as well as "listeners." You can instruct them to report their status via the bus, and they automatically send such a report when you power them up. Many vendors of IEEE-488 programmable supplies offer power systems that contain multiple supplies. Usually, an entire

Is programmable power the last bastion for linears?

The two technologies most often used to build fixed-output power supplies are linear regulation and off-line switching. Other technologies—some of them combinations of several regulation techniques—have gained more limited popularity. Two examples of these methods are the use of constant-voltage transformers and phase-controlled rectifiers to precede linear regulators, and the use of switching preregulators to drive regulating dc/dc converters.

Though off-line switching-regulator technology has made great inroads in the market for fixed-output power supplies, you may be surprised at how many programmable supplies still use linear regulation. (If you're interested in purchasing a particular supply and you need to know which regulation technique it uses, you'll probably have to ask the vendor. Data sheets for most programmable supplies don't mention the regulation techniques.) The reason that vendors have shown caution in embracing switching technology for programmable supplies is *not* that the small market encourages them to prolong the life of obsolete products. Rather, vendors have found it a challenge to design programmable switching supplies whose noise, transient response, and cost (at least for units that produce less than about 50W) are as good as those of high-quality linear supplies.

Period and pulse width determine resolution

For example, modern fixed-output off-line switchers often operate at frequencies of 100 kHz or higher, which are equivalent to a period of 10 μsec or less. They achieve regulation by varying the width of a pulse applied to an output filter. The minimum pulse width is determined by the turn-on and turn-off times of the switching elements—usually power FETs in low- and medium-power switchers of recent design. The characteristics of these FETs establish the minimum pulse width at approximately 100 nsec.

In a programmable switching supply with a pulse period of 10 μsec, a 100-nsec pulse width limits the control range to only 100:1. And no margin is left to compensate for the effects of line and load variations. A supply designer could, of course, lower the switching frequency to increase the control range. To keep the supply from emitting audible noise, however, you must keep the switching frequency at or above approximately 20 kHz. At 20 kHz, the control range is only 500:1, or 9 bits—a spec that's well below the output-voltage resolution requirements of many programmable supplies.

Fast programmable switchers are hard to design

Dynamic considerations don't favor programmable switchers either. The bandwidth of the control loop of a 20-kHz switcher forces the supply to take 500 μsec or more for output settling after you program a new voltage, or after a line-voltage or load-current change. Furthermore, the output filters used by many switchers are LC filters. Such filters tend to exhibit overshoot in their transient response unless the designer exercises special precautions, and those precautions tend to lower the supply's efficiency, which again casts doubt on the wisdom of choosing switching technology.

Finally, although there are many off-line switching-regulator topologies, and their performance differs, it's generally true that noise is greater in switching supplies than in linear ones. The noise voltage you observe at a switcher's output has a peak-to-peak value that depends strongly on the bandwidth of the device you use to make the observation; the fundamental noise frequency is usually twice the supply's switching frequency. You can argue that if the system to which the switcher supplies power is not bothered by disturbances at the noise's fundamental frequency and harmonics (at least when the disturbance amplitudes are as great as those the supply emits), you can ignore the switching noise.

power-supply system will reside at a single bus address, and individual supplies within the system will have subaddresses. This arrangement keeps as many bus addresses as possible open for controlling other instrumentation.

For this communication flexibility, however, you pay a penalty in programming speed, and you pay this penalty even for simpler and less-capable IEEE-488 power-supply interfacing schemes. The bus transactions by which you tell a supply what to do next often take more than 100 µsec. In many ATE applications, you can't tolerate such long delays.

You can program a supply more rapidly through a parallel interface that doesn't support the connection of multiple devices and doesn't allow for complex messages—for example, a parallel printer port of the

This argument may be valid when the system under test contains no analog elements. The problem is that the switching noise tends to appear everywhere within the system under test, and if there are analog elements, the noise casts doubt on most of the measurements you take.

You *can* control switching noise

Applications engineers for power-supply vendors will tell you that if you become knowledgeable about switchers and select and apply them with care, such noise problems need not plague you. For example, when you equip the lower-voltage members of Lambda's LR Series with the vendor's optional MRS Series filters, the supplies exhibit noise below 2 mV rms and 12 mV p-p in a 20-MHz bandwidth. (The LR Series supplies are available as components of programmable power-supply systems.) Few switchers achieve such low noise; on the other hand, many linear supplies do even better. Despite the existence of a few low-noise switchers such as these Lambda LRs, the idea of eliminating the switching noise by eliminating switching supplies appeals to many engineers.

If your system under test already uses switchers to supply power to its logic circuits, you're probably tempted to ask why it's important to make sure that no additional switching noise originates in the programmable supplies in the test equipment. The reason that you may want to avoid switchers is that the programmable supplies usually supply power to more sensitive portions of the system than do the logic supplies. Nonetheless, within some of the programmers that control the outputs of linear supplies, you can find examples of applications where switchers are perfectly acceptable in precision dc power systems. Some of these programmers use small switchers to power their own internal logic, even though linear supplies deliver the programmed voltages themselves.

Another question you may be tempted to ask is why a switcher shouldn't serve as a preregulator for a linear supply, thereby yielding a programmable supply that achieves the high efficiency of a switcher and the low noise and fast response of a linear supply. Some vendors who have unsuccessfully attempted this approach claim that it's all too easy to create a supply that combines the *worst* features of linear and switching supplies—high noise and slow response. Nevertheless, other vendors have successfully built such hybrid supplies.

One such vendor is Sorensen, which recently introduced the HPD series, a group of ¼-rack-width, 5¼-in.-high supplies that deliver 300W with 80% efficiency. These supplies' noise, though respectable, is not as low as that of some of the quietest linear supplies; the spec is 50 mV p-p in an unspecified bandwidth for models whose maximum outputs range from 15V to 60V. After a 50% increase or decrease in load current (in the range from 25% to 100% of full load), the outputs take 500 µsec to settle to the programmed value (within an error band whose width is ±0.05% of the supply's maximum output). When equipped with an IEEE-488 interface, HPD supplies list for $1645.

Switching noise originating within the supplies themselves isn't the only noise that can cause problems in programmable power systems, however. Transients that originate on the ac line and find their way, albeit in attenuated form, to the supply outputs can be a major problem. One vendor reports that a customer for burn-in supplies discovered that line transients were damaging 15% of the parts he was burning in. The supplies he was using had SCR preregulators followed by linear regulators. By changing to supplies that used switching preregulators, he was able to cut the device-failure rate to a fraction of 1%.

Digitally programmable supplies

The compact size *of programmable switching supplies is exemplified by this HPD Series supply from Sorensen. It produces 300W, and four of the units occupy just 5¼ in. of rack space. They are less than 12 in. deep.*

type found on most personal computers. But such printer ports only permit the transmission of data eight bits at a time. Parallel interfaces that accept wider words are faster still. Unfortunately, no industry standard governs them. Nonetheless, for maximum programming speed, several vendors offer proprietary parallel interfaces as an alternative to the IEEE-488 interface.

Of course, when a vendor configures a digitally programmable power-supply system from supplies that are also sold as stand-alone items, each supply almost surely has an analog programming input. For example, it may have a terminal that accepts a 0 to 10V signal to program the supply's output from 0 to 100% of the full rated value. You could, no doubt, design your own circuits to drive a supply's analog programming input. However, the reason that users opt for digitally programmable power supplies and power-supply systems is to avoid having to design their own interfaces. The task of designing such an interface is not trivial; isolating the analog programming output from the digital inputs is just one of the problems.

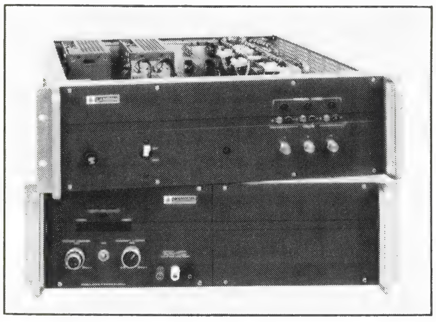
Electronic loads are versatile

In test-equipment applications, you don't always have to *supply* power to a load, as conventional single-quadrant supplies do, and 4-quadrant supplies can. Sometimes you only need to dissipate power from a power source, such as when you're testing a power supply. Electronic loads perform this function. Of course, resistors dissipate power too, and although resistors that can dissipate hundreds of watts or kilowatts are not inexpensive, especially when you consider the cost of mounting and cooling them, they usually cost less than electronic loads.

What electronic loads bring to the party is much greater application flexibility than resistors provide. An electronic load can operate as an adjustable constant-current sink, as a variable power resistor, and, in many cases, as an adjustable constant-voltage load. (The constant-voltage mode is useful for determining the V-I characteristics of devices that display negative resistance; for example, power supplies with foldback current limiting.) Now you can get IEEE-488-programmable electronic loads that are suitable for use in automatic test setups.

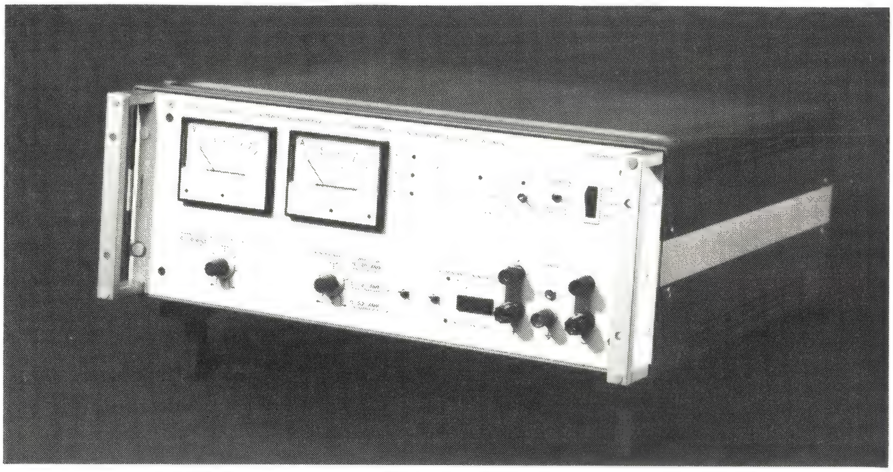
Load or function generator?

Some electronic loads incorporate even more advanced features, such as the ability to act as loads whose value (resistance, current, or voltage) is an arbitrary function of time that you can define yourself. Building an arbitrary waveform generator into an electronic load eliminates programming-related time delays when you change the load value. It also takes advantage of the



In configuring semicustom *programmable power systems, Lambda's applications engineers utilize off-the-shelf components such as the chassis, power supplies, and programming cards shown. The upper chassis houses programming cards and small supplies; the lower chassis accommodates one or more supplies that measure less than the full rack width.*

Digitally programmable supplies



Front-panel-mounted meters *that indicate a supply's status are features of many programmable supplies. This unit (from Rohde & Schwarz's NGPU Series) has analog meters, but other units sport digital displays.*

rapid response of electronic loads, many of which offer much faster response speed than do programmable power supplies. According to Glenn Green of Hewlett-Packard (Rockaway, NJ) the speed of electronic loads suggests that sometimes the best way to vary a dc source voltage rapidly is to team an electronic load operating in the programmed-voltage mode with a power supply operating as an adjustable constant-current source.

As they have with switching power supplies, power FETs have had an impact on the design of electronic loads. For example, one problem that plagued electronic loads whose output stages used bipolar power transistors was that the bipolar transistors would saturate when the loads operated at low voltages (for example, in testing of the 2V supplies used to power ECL). The devices that absorb the power dissipated in an electronic load must not saturate; if they do, you won't be able to control the load. Unlike bipolar transistors, FETs exhibit resistor-like behavior, so you can use an electronic load with a FET power stage to conduct tests in which the load voltage is

For more information . . .

For more information on the programmable dc power supplies and electronic loads discussed in this article, contact the following manufacturers directly, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service.

Electronic Measurements Inc
405 Essex Rd
Neptune, NJ 07753
(800) 631-4298
in AK, HI, and NJ
(201) 922-9300
TLX 132424
Circle No 700

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Cupertino, CA 95014
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Circle No 701

Kepco Inc
131-38 Sanford Ave
Flushing, NY 11352
(718) 461-7000
TWX 710-582-2631
Circle No 702

Lambda Electronics
515 Broad Hollow Rd
Melville, NY 11747
(800) 526-2324
or (800) 526-2325
TWX 510-224-6484
Circle No 703

Rohde & Schwarz
Muhldorfstrasse 15
8000 Munchen 80
West Germany (089) 41290
TLX 523703
Circle No 704

Rohde & Schwarz
4425 Nicole Dr
Lanham, MD 20706
(301) 459-8800
Circle No 705

Sorensen Co
5555 N Elston Ave
Chicago, IL 60630
(312) 775-0843
TWX 910-221-5199
Circle No 706

Transistor Devices Inc
274 S Salem St
Randolph, NJ 07869
(201) 361-8622
FAX 201-361-3615
Circle No 707

in the millivolt range.

To select the correct power supply or load for your application, you must know how manufacturers rate the power-handling capacity of electronic loads and the output capability of many of the wide-range supplies used in programmable power systems. Many of the loads spec both a maximum input voltage and a maximum input current, and many of the supplies have specs for both maximum output voltage and maximum output current. When you calculate the product of the maximum voltage and maximum current, the result is power that's much greater than the supply can produce or the load can dissipate. In such cases, the power rating of the unit is what's important.

If you're using the supply or load to produce or absorb a constant current, you can determine the maximum allowable terminal voltage by dividing the unit's power rating by the current in your application. If you're using the unit in constant-voltage mode, you determine the maximum allowable current by dividing the power rating by the terminal voltage. To avoid being misled, keep these rules in mind when you examine the specs in **Table 1.**

Because of the wide range of capabilities now available in digitally programmable power supplies, electronic loads, and power systems, the reasons for designing your own programmable power supply or load are dwindling. Within the next year, you'll probably see manufacturers adding programmable power modules to the library of units that plug into standard buses, providing even more diverse options for custom-ATE designers whose systems require modest amounts of programmable power. EDN

Article Interest Quotient
(Circle One)
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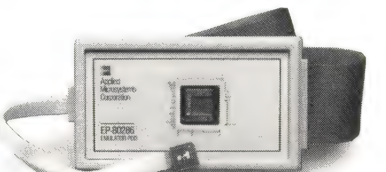

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In Japan, contact Applied Microsystems Japan Ltd., Nihon Seimei, Nishi-Gotanda Building, 7-24-5 Nishi-Gotanda, Shinagawa-KU, Tokyo T141, Japan. Telephone 03-493-0770. FAX 03-493-7270.

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Of course, the higher your production volume, the greater your savings. But the TC23SC can even cut costs on low volume applications, because it can simplify your ASIC design task immensely. You don't even have to need all 50,000 gates. the TC23SC Series includes a full range of sizes from 700 to 50,000 equivalent gates. It's simple to choose the optimum standard cell for your design.

Then there's the extensive library lineup. The TC23SC Series library, ADVANCELL™, is an ultra-high function LSI library. The full product lineup includes 166 primitive cell types, 108 74HC Series macrofunction types, and 67 I/O cell functional types. Macrocells include 2900 Series, CPU peripherals, multiplexers and more. Several RAM and ROM megacells are also available.

The TC23SC Series is fully supported by the VL-CAD system. The system is a CAD design tool developed by Toshiba with full support from logic design to autoplace and route.

BASIC CHARACTERISTICS		
PRODUCT LINEUP	TC22SC	TC23SC
	Macrocells & Macrofunctions	
LIBRARY	74HC Series Compatible Macrofunctions RAM ROM Functional Macros (PLA**, ALU, MPY)	ADVANCELL™ * RAM ROM Functional Macros (PLA**, ALU**, MPY, Barrel shifter, adder, FIFO**) 2900 Series Macros*** CPU Peripherals** Analog Macros***
PROCESS TECHNOLOGY	2μm	1.5μm
	HC²MOS Si-gate double layer metal	
MAXIMUM TOGGLE FREQUENCY	100MHz	150MHz
GATE SPEED (INNER GATE)	1.5ns	1.0ns
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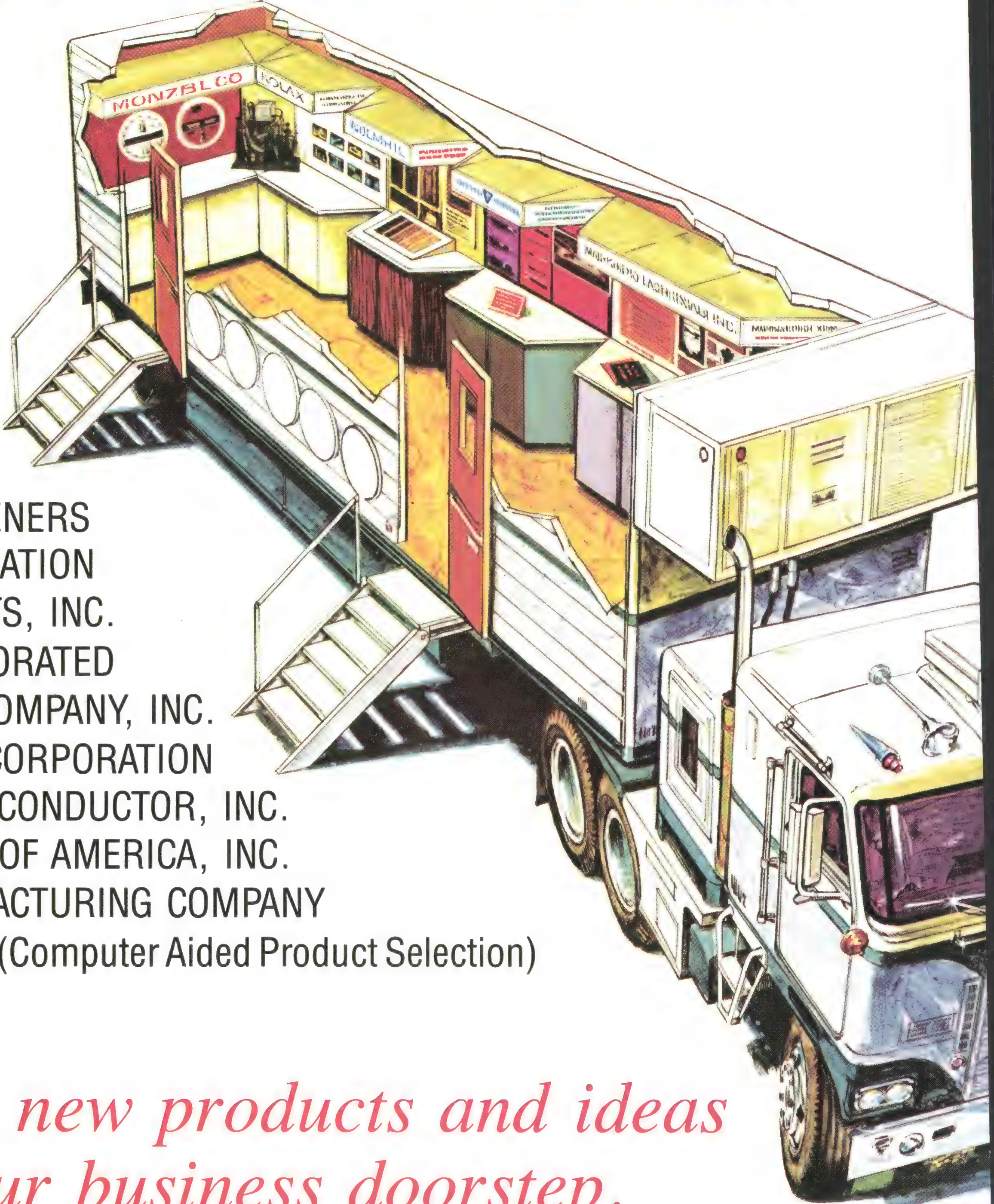

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ATE	TIME	SITE
/13 onday	9:00-11:00 AM	MOTOROLA INC., G.E.G.-Communications 8201 E. McDowell Rd., Scottsdale, AZ
/13 onday	11:30-1:00 AM-PM	MOTOROLA INC., G.E.G.-Tactical Electronics 8220 East Roosevelt St., Scottsdale, AZ
/13 londay	2:30-4:00 PM	MOTOROLA INC., G.E.G.-Strategic Electronics 2501 S. Price Rd., Chandler, AZ
/14 uesday	9:00-11:00 AM	HONEYWELL INC., Satellite Systems Division 19019 N 59th Ave., Glendale, AZ
/14 uesday	12:00-1:30 PM	HONEYWELL INC., Business & Computer Aviation 5353 W. Bell Rd., Glendale, AZ
/14 uesday	2:15-4:30 PM	HONEYWELL INC., Air Transport Systems 21111 N 19th Ave., Phoenix, AZ
/15 Vednesday	9:00-11:30 AM	HUGHES AIRCRAFT COMPANY, Missile Systems Old Nogales Hwy, Tucson, AZ
2/16 hursday	9:00-12:00 AM	GENERAL DYNAMICS Electronics Division Convair Dr. & Missile Rd., San Diego, CA
2/16 hursday	2:00-4:00 PM	CIPHER DATA PRODUCTS INC. 10101 Old Grove Rd., San Diego, CA
2/17 Friday	8:30-11:30 AM	M/A COM Government Systems 3033 Science Park Rd., San Diego, CA
2/17 Friday	1:30-4:00 PM	HUGHES AIRCRAFT COMPANY, IPD 6155 El Camino Real, Carlsbad, CA
2/20 Monday	9:00-11:00 AM	UNISYS CORPORATION 25725 Jeronimo Rd., Mission Viejo, CA
2/20 Monday	12:00-2:00 PM	HUGHES AIRCRAFT COMPANY-MSD Avenida Empressa, Rancho Santa Margarita, CA
2/20 Monday	3:00-4:30 PM	EMERSON ELECTRIC COMPANY, Industrial Controls 3300 S. Standard, Santa Ana, CA
2/21 Tuesday	9:00-12:00 AM	FORD AEROSPACE & COMMUNICATIONS CORPORATION Ford Rd., Newport Beach, CA
2/21 Tuesday	1:30-3:30 PM	McDONNELL DOUGLAS ASTRONAUTICS COMPANY 5301 Bolsa Ave., Huntington Beach, CA
2/22 Wednesday	9:00-11:00 AM	HUGHES AIRCRAFT COMPANY, Support Systems Hughes Way, Long Beach, CA
2/22 Wednesday	12:00-3:00 PM	McDONNELL DOUGLAS AIRCRAFT COMPANY 3855 Lakewood Blvd., Long Beach, CA
2/23 Thursday	9:00-11:30 AM	ROCKWELL INTERNATIONAL Defense Electronics 3370 Miraloma Ave., Anaheim, CA
2/23 Thursday	1:00-3:30 PM	HUGHES AIRCRAFT COMPANY, Ground Systems 1901 W. Malvern Ave., Fullerton, CA
2/24 Friday	8:30-11:30 AM	TRW, INC., Electronic Systems Group One Space Park, Redondo Beach, CA
2/24 Friday	1:00-3:00 PM	MAGNAVOX Advanced Products & Systems 2829 Maricopa St., Torrance, CA
2/27 Monday	9:00-11:30 AM	GENERAL DYNAMICS, Pomona Division 1675 W. Mission, Pomona, CA
2/27 Monday	1:30-3:30 PM	BECKMAN INSTRUMENTS INCORPORATED 200 S. Kraemer Blvd., Brea, CA
2/28 Tuesday	8:00-10:00 AM	NORTHROP CORPORATION Advanced Systems Division 8900 E. Washington Blvd., Pico Rivera, CA
2/28 Tuesday	11:00-1:00 AM-PM	NORTHROP CORPORATION Electronics Division 2301 W. 120th St., Hawthorne, CA
3/1 Wednesday	8:30-10:30 AM	XEROX CORPORATION 701 S. Aviation Blvd., El Segundo, CA
3/1 Wednesday	11:30-1:00 AM-PM	HUGHES AIRCRAFT COMPANY, Electro Optical Div. 2000 E. El Segundo Blvd., El Segundo, CA
3/1 Wednesday	2:30-4:00 PM	OCEAN TECHNOLOGY INC. 2835 Naomi St., Burbank, CA
3/2 Thursday	9:00-11:00 AM	LITTON DATA SYSTEMS 15927 Strathern Ave., Van Nuys, CA
3/2 Thursday	1:00-4:00 PM	TELEDYNE SYSTEMS COMPANY INC. 19601 Nordhoff St., Northridge, CA
3/3 Friday	9:00-11:00 AM	TELEDYNE ELECTRONICS 649 Lawrence Dr., Newbury Park, CA
3/3 Friday	1:00-3:30 PM	DELCO SYSTEMS OPERATIONS 6767 Hollister Ave., Goleta, CA

DATE	TIME	SITE
3/6 Monday	9:00-11:00 AM	AMPEX CORPORATION 401 Broadway, Redwood City, CA
3/6 Monday	12:30-3:00 PM	FORD AEROSPACE & COMMUNICATIONS CORPORATION Fabian Way, Palo Alto, CA
3/7 Tuesday	9:00-11:00 AM	FORD AEROSPACE & COMMUNICATIONS CORPORATION 1260 Crossman Ave., Sunnyvale, CA
3/7 Tuesday	12:00-1:30 PM	GTE GOVERNMENT SYSTEMS 100 Ferguson Dr., Mountain View, CA
3/7 Tuesday	2:30-4:00 PM	NORTHERN TELECOM INC. 2305 Mission College Blvd., Santa Clara, CA
3/8 Wednesday	8:30-11:30 AM	APPLE COMPUTER, INC. 20525 Mariani Ave., Cupertino, CA
3/8 Wednesday	2:30-4:00 PM	TANDEM COMPUTERS INC. 19333 Vallco Pkwy., Cupertino, CA
3/9 Thursday	8:30-10:30 AM	AMDAHL CORPORATION, Telecommunications Div. 1250 E. Argues Ave., Sunnyvale, CA
3/9 Thursday	11:30-1:30 AM-PM	HEWLETT-PACKARD COMPANY 5301 Stevens Creek Blvd., Santa Clara, CA
3/9 Thursday	2:00-3:30 PM	VERSATEC INC. 2710 Walsh Avenue, Santa Clara, CA
3/10 Friday	9:00-11:00 AM	FORD AERO., Western Development Labs 220 Henry Ford II Dr., San Jose, CA
3/10 Friday	2:00-4:00 PM	HEWLETT-PACKARD COMPANY, Network Measurement Div. 1400 Ftn.-Grove Pkwy., Santa Rosa, CA
3/13 Monday	9:00-11:00 AM	HEWLETT-PACKARD COMPANY, Portable Computer Div. 1000 NE Circle Blvd., Corvallis, OR
3/13 Monday	1:30-3:30 PM	TEKTRONIX, INC. Parkway Ave., Wilsonville, OR
3/14 Tuesday	8:30-11:00 AM	TEKTRONIX, INC. Murray Rd., Beaverton, OR
3/14 Tuesday	11:30-1:00 AM-PM	TEKTRONIX, INC. Walker Rd., Beaverton, OR
3/14 Tuesday	2:15-4:15 PM	TEKTRONIX, INC. Clark County, Camas, WA
3/15 Wednesday	9:00-11:00 AM	HONEYWELL, INC., Marine Systems 6500 Harbour Hgts. Pkwy., Everett, WA
3/15 Wednesday	12:00-2:00 PM	ELDEC CORPORATION Martha Lake Campus, Lynnwood, WA
3/15 Wednesday	2:30-4:00 PM	ELDEC CORPORATION N. Creek Campus, Bothel, WA
3/16 Thursday	9:00-11:00 AM	SUNDSTRAND DATA CONTROL INC. 15001 NE 36th St., Redmond, WA
3/16 Thursday	1:00-3:30 PM	PHYSIO CONTROLS CORPORATION 11811 Willows Rd., Redmond, WA
3/17 Friday	9:00-12:00 AM	BOEING ELECTRONICS Lind Ave. & 39th St., Seattle, WA
3/17 Friday	1:30-4:00 PM	BOEING AEROSPACE COMPANY 20403 68th Ave. South, Kent, WA
3/20 Monday	9:00-12:00 AM	UNISYS CORPORATION 322 North 2200 West, Salt Lake City, UT
3/21 Tuesday	11:00-1:00 AM-PM	HEWLETT PACKARD COMPANY 3404 E. Harmony Road, Ft. Collins, CO
3/21 Tuesday	2:00-4:00 PM	HEWLETT-PACKARD COMPANY 815 14th St. S.W., Loveland, CO
3/22 Wednesday	8:30-10:30 AM	MINISCRIBE CORPORATION 1871 Lefthand Circle, Longmont, CO
3/22 Wednesday	11:30-1:00 AM-PM	STORAGE TECHNOLOGY CORPORATION 2270 S. 88th St., Louisville, CO
3/22 Wednesday	2:00-4:00 PM	AT&T BELL LABORATORIES 11900 N. Pecos St., Denver, CO
3/23 Thursday	8:30-11:00 AM	DIGITAL EQUIPMENT CORPORATION 301 Rockrimmon Blvd., Colorado Springs, CO
3/23 Thursday	12:00-1:30 PM	HEWLETT-PACKARD COMPANY, Logic Systems Div. 8245 N. Union St., Colorado Springs, CO
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MW	85-132/	50W	3	1.0	6.1	3.7
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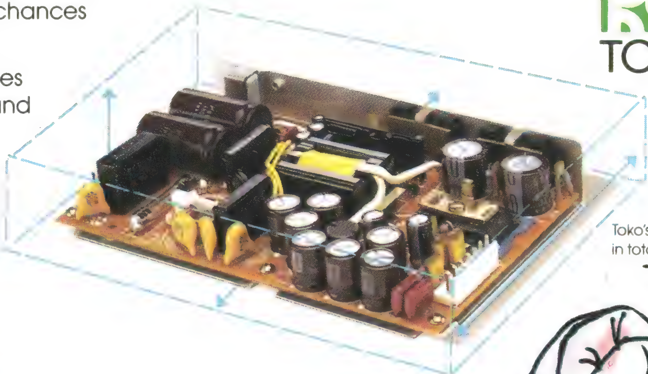

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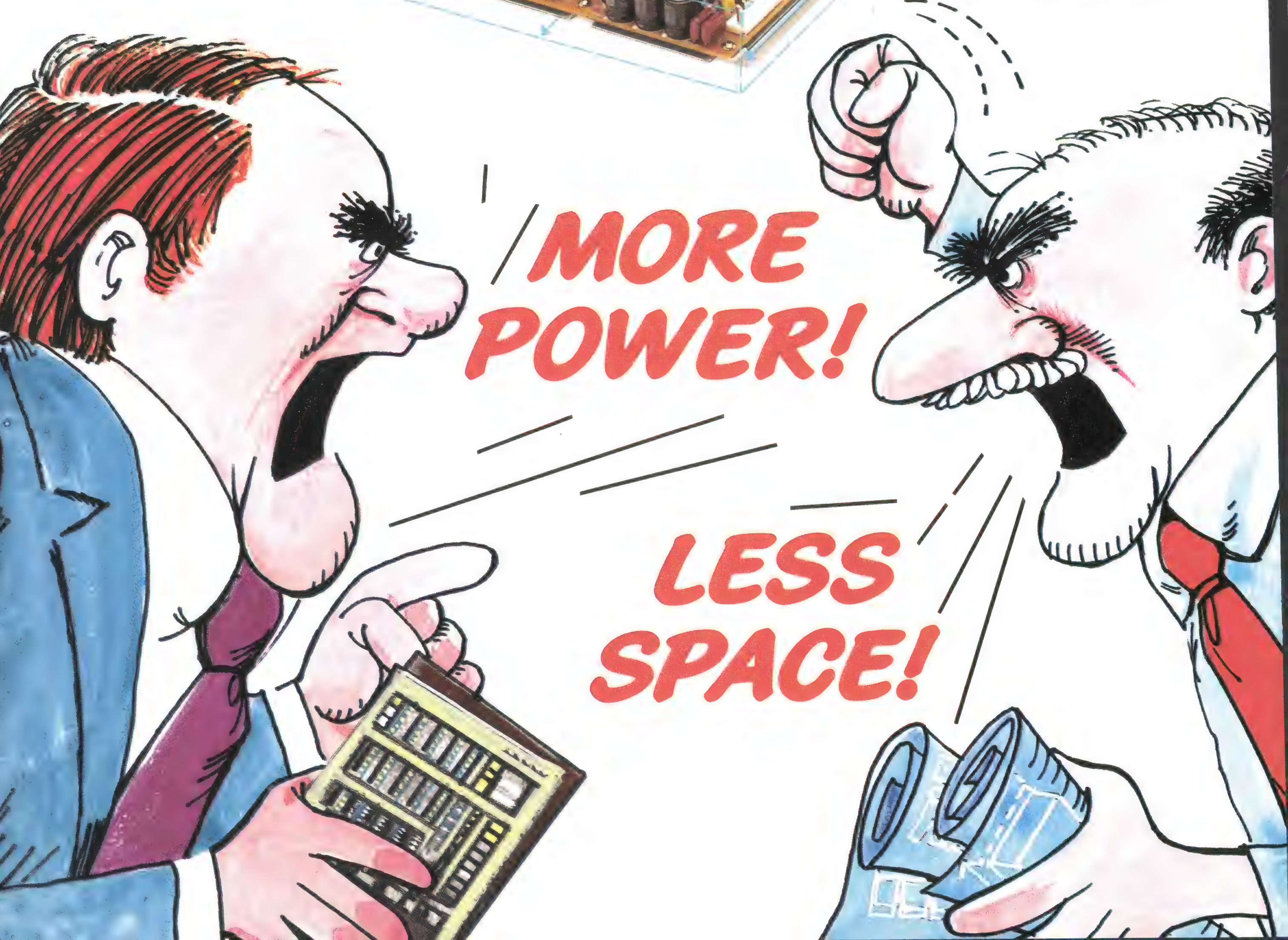


Bus-analysis tools isolate tough problems

When cards on a bus refuse to work together, bus analyzers and related tools can help you hunt down and eradicate the problem.

Steven H Leibson,
Regional Editor

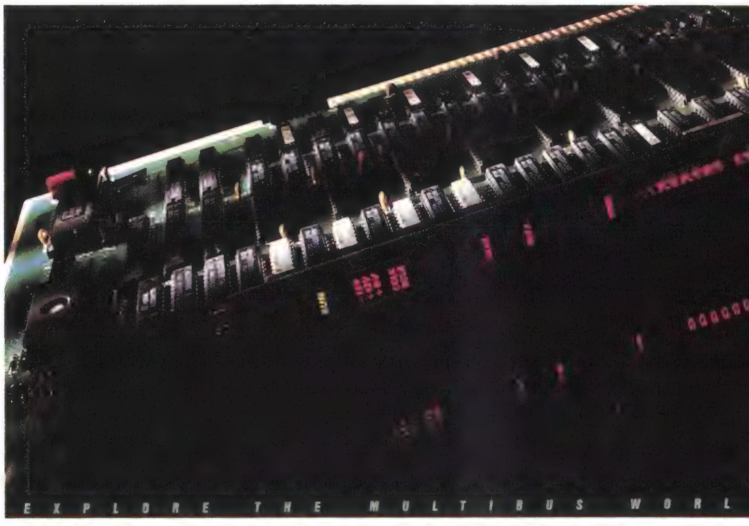
If your systems incorporate standard microcomputer or minicomputer backplane buses, consider adding some of the troubleshooting aids specifically designed for those buses to your troubleshooter's toolbox. General-purpose logic analyzers can help you locate and resolve bus-related malfunctions, but bus-analysis tools tailored to a particular computer bus augment a logic analyzer's capabilities and can often help you identify the problem more quickly.

Bus-analysis tools fall into one of two broad categories: bus adapters designed to mate with general-purpose logic analyzers, and board-based bus analyzers. A bus adapter works with a general-purpose logic analyzer and simplifies the connection of the analyzer to a standard computer bus. A board-based bus analyzer replicates many of the capabilities of a general-purpose logic analyzer, and features capabilities, such as symbolic disassembly of bus states, that are matched to a specific bus. In addition, several companies offer other specialized troubleshooting tools for various microcomputer buses that assist you in the debugging process.

If you have a general-purpose logic analyzer, the chances are good that you've used it to observe bus transactions when searching for a problem. Because you're intent on finding the malfunction and its cause, the task of connecting a large number of test clips to a backplane often seems overly time consuming. The task's potential for error is high, therefore, both because you'll be tempted to do it hastily and simply because 32-bit buses have so many signals.

Perhaps you've had the frustrating experience of finding what you think is a bus-transaction problem, only to discover that you connected a logic probe to the wrong signal or mistakenly swapped two probes when connecting them to the backplane. Or worse, you may have watched helplessly as a precariously perched test pod fell, tearing your carefully placed test clips off the backplane.

Bus adapters help you avoid such problems by simplifying the connection between the logic analyzer and the backplane. **Table 1** lists a variety of bus

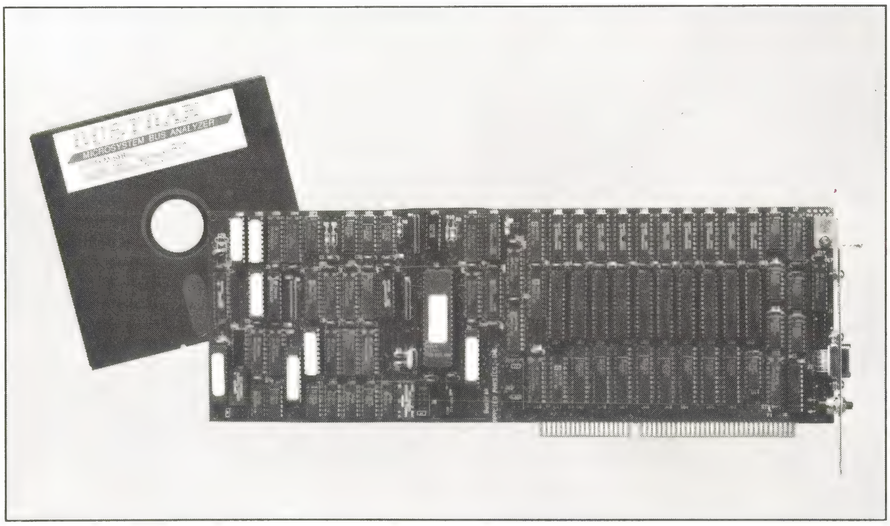


Board-based bus analyzers *give you a simple, convenient window for observing minicomputer or microcomputer bus operations. (Photo courtesy Silicon Control Inc)*

adapters for several minicomputer and microcomputer buses. These products plug directly into a backplane bus, and they make some provision for directly connecting to a logic analyzer's probe pods without using the wire probes that are so easy to disconnect or misconnect.

Do it right the first time

Bus adapters have an added advantage—they encourage you to connect your logic analyzer to *all* of the backplane's logic signals in a standardized manner by making the connection process much simpler and less time consuming. Thus, you won't be faced with the unhappy possibility of eliciting a system malfunction (which in itself can be quite difficult) and causing the logic analyzer to trigger, yet failing to capture the fault condition because the errant bus signal doesn't happen to be hooked up to one of the analyzer's acquisition channels.



The well-defined environment of the IBM PC *allows vendors of bus analyzers for the PC bus to include comprehensive test software with their hardware. (Photo courtesy Applied Physics Inc)*

You may also recall a time or two when you've misinterpreted the captured data because the bus-signal names didn't appear on your logic analyzer's display. To alleviate some of these problems, several of the bus adapters listed in **Table 1** include bus-transaction disassembly software for specific logic analyzers. This software can label individual traces with the appropriate bus-signal names and can recognize spe-

TABLE 1—REPRESENTATIVE LOGIC-ANALYZER BUS ADAPTERS

BUS	MANUFACTURER	MODEL	BUS-CYCLE DISASSEMBLER	SUPPORTED LOGIC ANALYZERS	PRICE	COMMENTS
MULTIBUS	HEWLETT-PACKARD	HP 52126A	NO	HP 1650A HP 16510A	$370	REQUIRES THE $270 HP 10320C INTERFACE AND THE $470 HP 10269C GENERAL-PURPOSE PROBE INTERFACE
Q BUS	HEWLETT-PACKARD	HP 10276A	NO	HP 1650A HP 16510A	$520	REQUIRES THE $270 HP 10320C INTERFACE AND THE $470 HP 10269C GENERAL-PURPOSE PROBE INTERFACE
	GOULD	A14581	NO	K SERIES	$2000	SERIES TERMINATION OF ALL SIGNALS AT THE BUS
	KONTRON	LA-CQBUS	YES	LA SERIES	$1595	PRICE INCLUDES PROBE-ADAPTER CARD AND DISASSEMBLY SOFTWARE. REQUIRES $250 UPR-10 PROBE RACK
	TEKTRONIX	91TM52	YES	DAS 9100	$350	DISASSEMBLER SOFTWARE ONLY; NO PROBE INTERFACE HARDWARE
STD BUS	TEKTRONIX	PM405	YES	1220/25/30	$600	PRICE INCLUDES PROBE-ADAPTER HARDWARE AND DISASSEMBLER SOFTWARE
UNIBUS	HEWLETT-PACKARD	HP 10275A	NO	HP 1650A HP 16510A	$470	REQUIRES THE $270 HP 10320C INTERFACE AND THE $470 HP 10269C GENERAL-PURPOSE PROBE INTERFACE
	TEKTRONIX	91TM51	YES	DAS 9100	$350	DISASSEMBLER SOFTWARE ONLY; NO PROBE INTERFACE HARDWARE
VAXBI	TEKTRONIX	VB100	YES	DAS 9100	$9250	PRICE INCLUDES PROBE-ADAPTER HARDWARE AND DISASSEMBLER SOFTWARE
VME BUS	GOULD	A14605 VIC	NO	K450B	$2000	COMPANY ALSO SELLS CUSTOM VERSION OF THE VBAT VME BUS TRIGGER BOARD FOR $2000

cific bus transactions, making triggers easier to configure. Thus, you could set an analyzer loaded with such disassembly software to trigger (for example) if an interrupt on bus signal IRQ7 occurs, instead of specifying the trigger as a high-to-low transition on probe channel 3, pod 4.

High costs create a niche

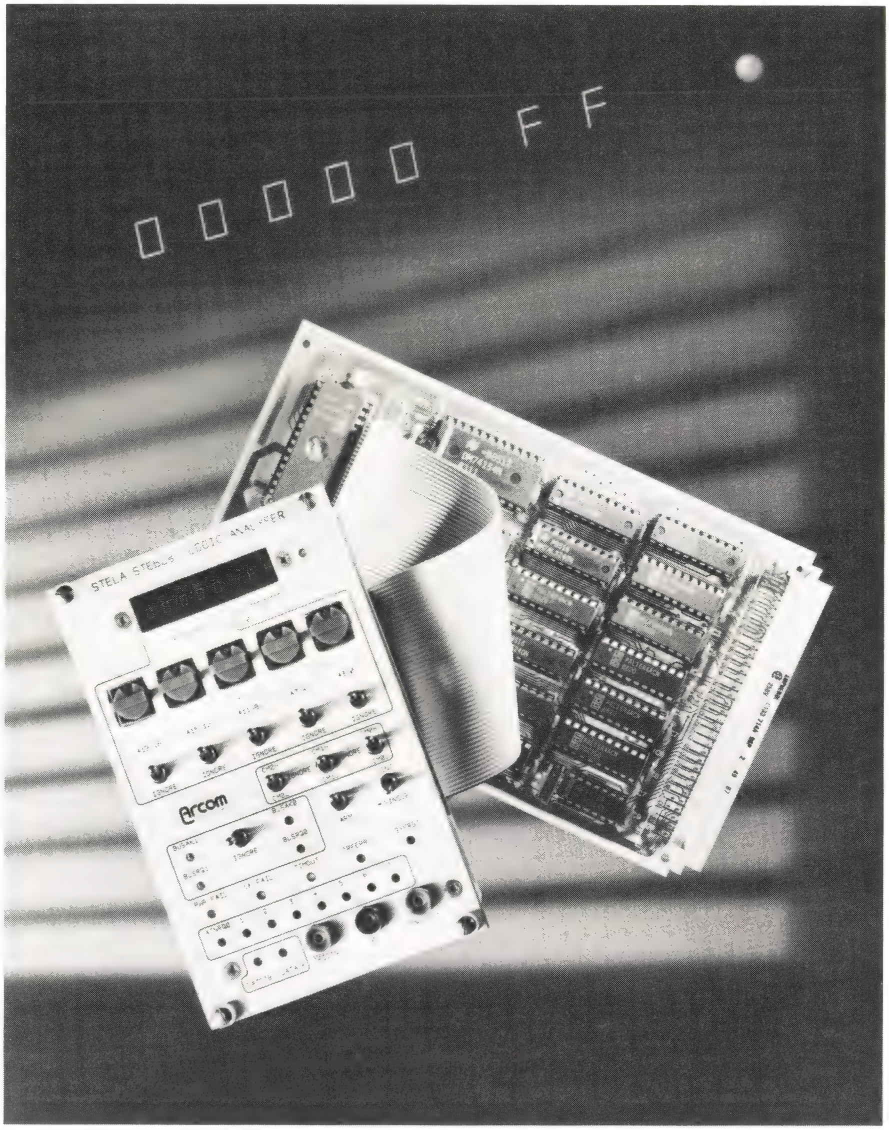
The combination of a full-featured logic analyzer and a bus adapter offers excellent performance, but price is another matter. The cost for one of the bus adapters listed in **Table 1** plus the associated logic analyzer can exceed $5000, and may top $10,000.

Because those prices are so high, many designers turn to board-based bus analyzers, which lack such frills as power supplies and cases and are streamlined for one particular task—troubleshooting systems based on standard buses. Therefore, they generally cost substantially less than general-purpose logic analyzers. **Table 2** lists several board-based bus analyzers that are available for various microcomputer buses.

Many board-based bus analyzers incorporate very wide and very deep state memories, and some even offer such features as multiple trigger levels and storage qualifiers. Therefore, even though they may lack some of the capabilities of full-featured logic analyzers, board-based bus analyzers can provide substantial assistance when you're hunting down hardware and software problems in bus-based systems.

Have bus analyzer, will travel

By using a low-cost, board-based bus analyzer to troubleshoot bus-related problems in the lab, you can free your general-purpose analyzer for other work. It's also much easier to pack a board-based analyzer in a suitcase to troubleshoot problems in the field than it is to lug around a general-purpose analyzer.



***You can recreate the lights-and-switches look and feel** of early minicomputers with bus-analysis tools that include front panels. One such tool is Arcom Control Systems Ltd's STELA for the STE Bus.*

Board-based analyzers for the IBM PC bus fall into two categories. Products from Microcase's Atron Div and from The Periscope Co target software development and debugging. Both these companies offer extensive software support for symbolic code disassembly, and their products perform many of the functions of in-circuit emulators. In contrast, the software supplied with the Bustrak from Applied Physics makes the product more closely resemble a general-purpose state analyzer.

Because μPs and software are not nearly as standardized for other microcomputer buses as they are for systems based on the IBM PC bus, board-based bus analyzers for these other buses focus on state analysis rather than software debugging. In addition, all of the board-based VME Bus analyzers listed in **Table 2** provide timing-and

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state-analysis capabilities.

Though they don't perform bus-timing or bus-state analysis, a variety of bus-specific tools perform simpler, yet important, troubleshooting tasks. A representative list of such products appears in **Table 3**.

One example of such a product is the Postcard from Award Software, which captures and displays POST (power-on self-test) codes written out to a specific I/O port address by the computer's BIOS (basic I/O system) ROM during the power-on sequence. This little half-card for the IBM PC bus allows you to monitor the progress of the BIOS self-test without setting any switches or connecting any test probes. You can use the Postcard as a low-cost tool for troubleshooting a balky PC mother board in the lab or in the field, and you can also use it as a status monitor during the burn-in phase of your manufacturing process.

Similarly, the MB100 from Silicon Control and the ZX-906B from Zendex, the STELA from Arcom, and the CVMEBM1 from Concise Technology can latch and display a single bus cycle on a group of LEDs for the Multibus, the STE Bus, and the VME Bus, respectively. Although capturing a single bus transaction may not qualify as bus-state analysis, these boards can be quite helpful when all you need to know is whether a certain address location is ever accessed and what data was read from or written to that location. Essentially, these products allow you to add lights and switches to a microcomputer for much the same diagnostic reason that early minicomputers had front panels festooned with lights: When the indicators stop blinking, you know that something has probably gone awry.

Beyond bus analysis

Complex buses such as the VME Bus support transactions other than simple data transfers and interrupts. The VME Bus accommodates distributed interrupt handlers and multiple bus masters. These VME Bus features allow you to create complex, multiprocessor systems

Alternative sources

Bus-analysis tools represent a fairly small market, so many manufacturers of these products employ alternative distribution channels for their wares. For example, VMEtro and Gould both sell Ultraview's VBAT board as a bus-analyzer accessory. Nissho markets Silicon Control's board-based bus analyzers under its own brand name. And bus-analysis tools from two British companies, Concise Technology and Arcom, are marketed in the US by C&C Technology and Val-Tech, respectively.

TABLE 2—REPRESENTATIVE BOARD-BASED BUS ANALYZERS

BUS	MANUFACTURER	MODEL	STORAGE/ DISPLAY CHANNELS	CHANNEL DEPTH (WORDS)	ADDRESS	TRIGGERS DATA	CONTROL SIGNALS	SEQUENTIAL LEVELS	EVENT TIMER/COUNTER
IBM PC BUS	APPLIED PHYSICS	BUSTRAK	80	8000	RANGE	YES	YES	NO	NO
	MICROCASE/ ATRON	PROBE-386	80	8k	RANGE	YES	NO	4 HARDWARE, 16 SOFTWARE	NO
		PROBE-AT	56	8k	RANGE	YES	NO	4 HARDWARE, 16 SOFTWARE	NO
	PERISCOPE	PERISCOPE III	48	8k	16 RANGES	16 RANGES	NO	NO	NO
MULTIBUS	SILICON CONTROL	MB110	64	8k	RANGE	RANGE	YES	NO	NO
	ZENDEX	ZX-907	40	1k	YES	NO	YES	NO	NO
NUBUS	APPLIED PHYSICS	BUSTRAK	48	32k	RANGE	RANGE	YES	NO	NO
VME BUS	SILICON CONTROL	VME110	96	2k	MULTIPLE WINDOWS	MULTIPLE WINDOWS	YES	4	YES
	VMETRO	VBT-320A	96	2k	INSIDE OR OUTSIDE A WINDOW	ANY BYTE	32	NO	YES
		VBT-321	96	2k	INSIDE OR OUTSIDE A WINDOW	ANY BYTE	32	4	YES

that are often tough to debug. If you should encounter problems with such a system during development, you might need to know which processor card had control of the VME Bus when the malfunctions occurred. Traditional state-analysis techniques may provide that information—as long as the bus analyzer happened to capture the most recent bus-arbitration cycle in its memory. You aren't always that lucky, however.

Concise Technology's CVMEOM1 VME Bus ownership module (listed

TABLE 3—REPRESENTATIVE BUS-TROUBLESHOOTING AIDS

BUS	MANUFACTURER	MODEL	STORAGE/ DISPLAY CHANNELS	CHANNEL DEPTH (WORDS)	ADDRESS	TRIGGERS DATA	CONTROL SIGNALS	USER INTERFACE	PRICE	COMMENTS
IBM PC	AWARD	POSTCARD	8	1	NA	NA	NA	LEDs	$399	DISPLAYS STATUS OF POWER-ON SELF-TEST (POST)
MULTIBUS	SILICON CONTROL	MB100	64	1	NO	NO	YES	LED DISPLAY	$595	POWER MONITORS
	ZENDEX	ZX-906B	52	1	YES	NO	YES	LED DISPLAY	$655	POWER SUPPLY MONITOR, SINGLE-STEP CAPABILITY
STE BUS	ARCOM	STELA	47	1	YES	NO	YES	LED DISPLAY	$620	EXTERNAL TRIGGER INPUT AND OUTPUT
VME BUS	CONCISE TECH	CVMEBM1	96	1	NO	NO	YES	LED DISPLAY	$2995	EXTERNAL TRIGGER, CYCLE STRETCHING, SINGLE-STEP
		CVMEOM1	NA	NA	NA	NA	NA	LED DISPLAY	$2995	INDICATES SLOT NUMBER OF ACTIVE BUS OWNER AND INTERRUPT HANDLER
		CVMEB51	NA	NA	NA	NA	NA	LED DISPLAY	$1995	BUS STIMULATOR: GENERATES INTERRUPTS AND POWER-FAIL SIGNALS
	ULTRAVIEW	VBAT	98	NA	NO	NO	YES	LED DISPLAY	$1995	AUTOMATICALLY GENERATES TRIGGERS FOR VME BUS TIMING VIOLATIONS

NOTE:
NA=NOT APPLICABLE

STORE QUALIFIER	MAX SAMPLE RATE	STATE ANALYSIS	TIMING ANALYSIS	USER INTERFACE	PRICE	COMMENTS
NO	10 MHz	YES	NO	SCREEN DISPLAY	$1495	CONTINUOUSLY VARIABLE TRIGGER POSITION
YES	25 MHz	YES	NO	SCREEN DISPLAY OR RS-232C PORT	$3995	INCLUDES SYMBOLIC DISASSEMBLER; WORKS WITH MICROSOFT WINDOWS; WORKS WITH PROTECTED-MODE SOFTWARE
NO	10 MHz + 1 WAIT STATE	YES	NO	SCREEN DISPLAY OR RS-232C PORT	$2495	INCLUDES SYMBOLIC DISASSEMBLER; WORKS WITH MICROSOFT WINDOWS; WORKS WITH PROTECTED-MODE SOFTWARE
NO	10 MHz + 1 WAIT STATE	YES	NO	SCREEN DISPLAY	$1395	INCLUDES DISASSEMBLER, 16-BIT PASS COUNTER
YES	10 MHz	YES	NO	LED DISPLAY, RS-232C PORT	$1595	2 EXTERNAL TRIGGER INPUTS, POWER MONITORS
NO	10 MHz	YES	NO	RS-232C PORT	$715	TRIGGER AT BEGINNING OR END OF SAMPLE
NO	10 MHz	YES	NO	SCREEN DISPLAY	$2495	EXTERNAL TRIGGER INPUT AND OUTPUT, 5 EXTRA CAPTURE CHANNELS
YES	20 MHz	ASYNC	YES	RS-232C PORT	$3495	EXTERNAL TRIGGER, TRIGGER POSITIONING
YES	16 MHz	ASYNC	YES	RS-232C PORT	$3950	AVAILABLE WITH 72 CHANNELS FOR $3350
YES	25 MHz	ASYNC	YES	RS-232C PORTS	$5900	EXTERNAL TRIGGER INPUT, 32 SETUPS IN NONVOLATILE RAM

in **Table 3**) solves this particular VME Bus troubleshooting problem. The CVMEOM1 plugs into a VME Bus slot and couples to jumper pins on the VME Bus backplane with additional cables. This cabling allows the ownership module to monitor the daisy-chained bus-grant and interrupt-acknowledge signal lines, and thus determine which VME Bus slot holds the card containing the bus master or interrupt handler that's currently controlling the bus. The CVMEOM1 accommodates VME Bus backplanes having as many as 21 slots.

The last product listed in **Table 3** also performs a very specialized function for the VME Bus. Ultraview designed its VBAT board to generate a trigger pulse when it detects a signal-timing violation on the VME Bus. The VBAT can detect 27 different classes of timing problems. You use the VBAT output pulse as a trigger for a logic analyzer or a digital sampling oscilloscope (DSO). The VBAT incorporates 104 rule-based trigger circuits that monitor the timing on 94 VME Bus lines simultaneously, providing many more trigger conditions than even top-of-the-line logic analyzers can support.

The VME Bus specification (IEEE standard 1014-1987) carefully lists timing rules for all VME Bus cycles, and the VBAT continuously monitors the bus traffic for timing violations. Should a violation occur, the VBAT will trigger the attached analyzer or DSO and will also light one of 40 LEDs to show which rule has been violated.

Fig 1 gives an example of the VBAT's trigger capabilities. The top trace shows the least significant VME Bus data line (D00) and the bottom trace shows the associated data strobe DS0*. This particular display from a DSO shows a spike

For more information . . .

For more information on the bus-analysis products discussed in this article, circle the appropriate numbers on the Information Retrieval Service card, contact the following manufacturers directly, or use EDN's Express Request service.

Applied Physics
Box 2368
West Lafayette, IN 47906
(317) 497-1718
Circle No 708

Arcom Control Systems Ltd
Unit 8, Clifton Rd
Cambridge CB1 4WH, UK
(0223) 411200
FAX (0223) 410457
TLX 94016424
Circle No 709

Award Software Inc
130 Knowles Dr
Los Gatos, CA 95030
(408) 370-7979
FAX (408) 370-3399
Circle No 710

C&C Technology
Box 280
Batavia, IL 60510
(312) 879-7003
TLX 4974811
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Treforest Industrial Estate
Pontypridd, Mid
Glamorgan CF37 5YG, UK
(0443) 841202
TLX 94017592
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Gould Inc
Test & Measurement Div
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TWX 910-338-0509
Circle No 713

Hewlett-Packard Co
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Palo Alto, CA 94303
Phone local office
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Kontron Electronics Inc
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Mountain View, CA 94039
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TWX 910-378-5207
Circle No 715

Kontron Messtechnik GmbH
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FAX (01865) 77-512
TLX 526719
Circle No 716

Microcase
Atron Div
Saratoga Office Center
12950 Saratoga Ave
Saratoga, CA 95070
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FAX (408) 253-5946
TLX 989339
Circle No 717

Nissho Electronics (USA) Corp
Inwood Park, Suite 200
17310 Red Hill Ave
Irvine, CA 92714
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FAX (714) 261-8819
TLX 181308
Circle No 718

The Periscope Co Inc
1197 Peachtree St, Plaza Level
Atlanta, GA 30361
(404) 875-8080
Circle No 719

Silicon Control Inc
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Northbrook, IL 60062
(312) 634-9313
Circle No 720

Tektronix Inc
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Beaverton, OR 97077
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FAX (503) 627-5139
TWX 910-467-8708
TLX 151754
Circle No 721

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Fremont, CA 94539
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Val-Tech Inc
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Newark, DE 19714
(302) 738-0500
FAX (302) 738-6594
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47 2 39 46 90
FAX 47 2 18 39 38
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Houston, TX 77042
(713) 266-6430
FAX (713) 266-6919
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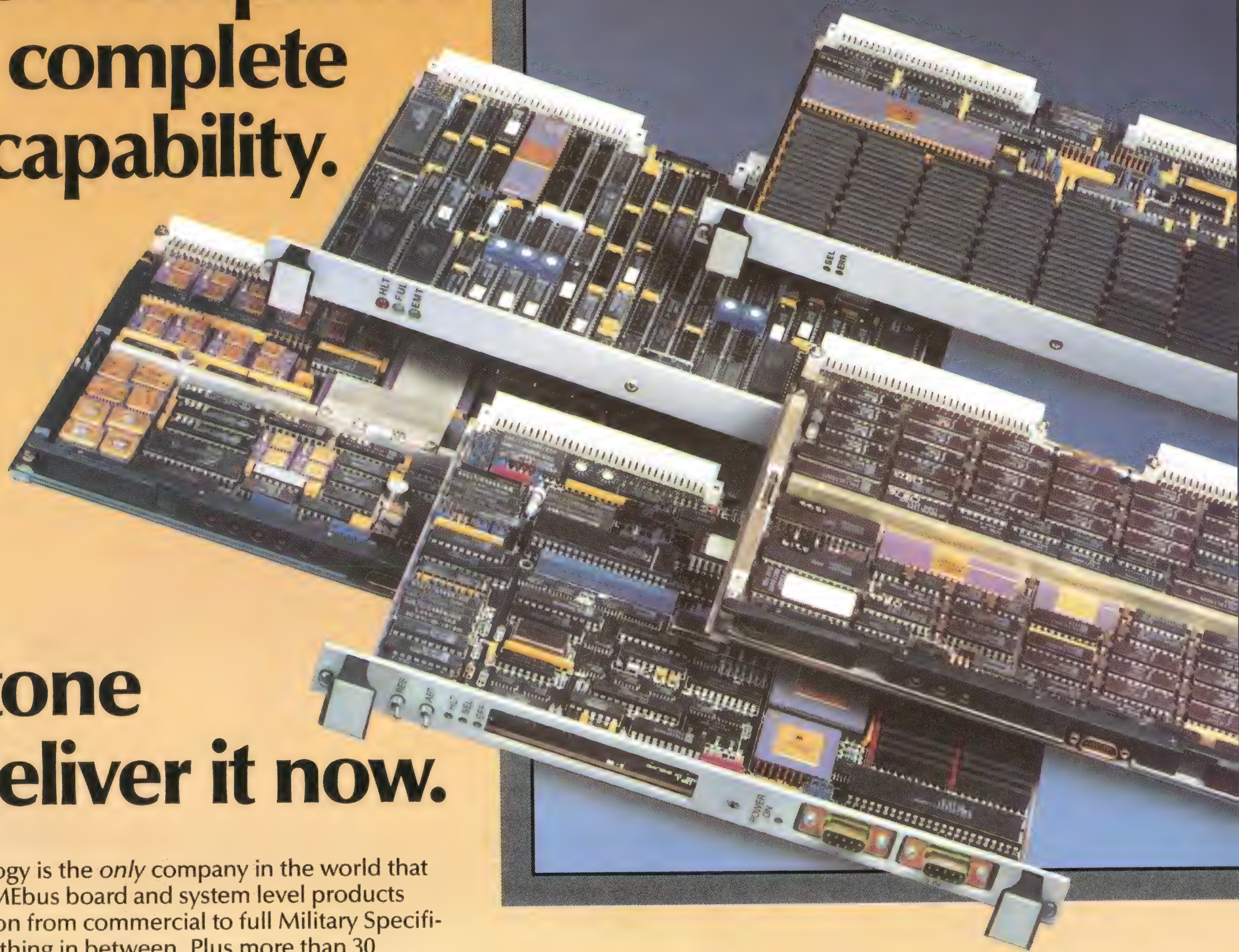

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Bus-analysis tools

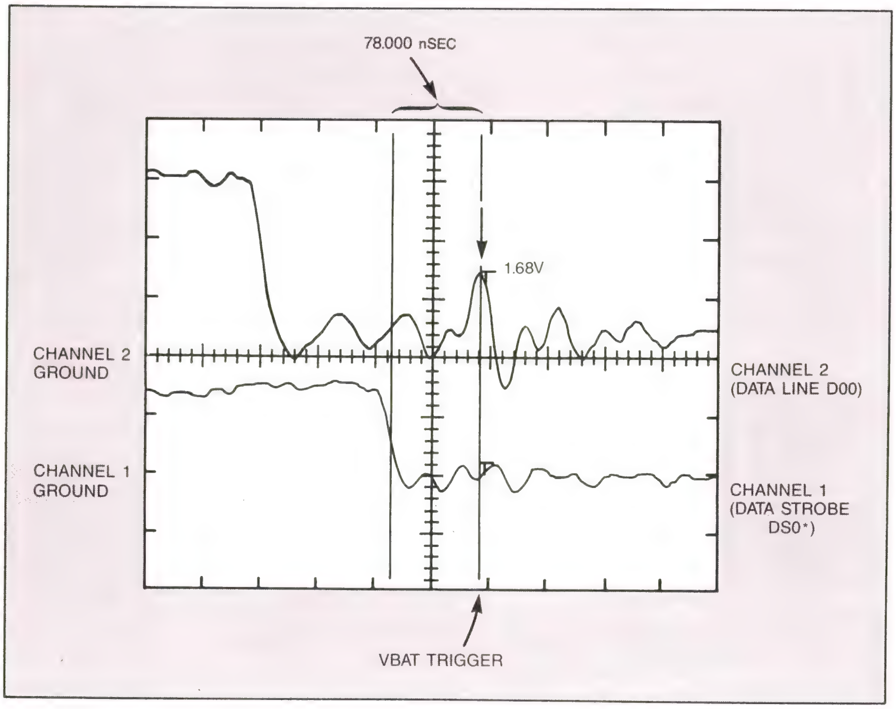

Fig 1—A timing violation is caught in the act *by an Ultraview VBAT trigger board and a digital sampling oscilloscope. The spike on the least significant VME Bus data line (upper trace) caused the data line to exceed a TTL logical-zero voltage level while the data strobe, DS0* (lower trace), was asserted (low).*

occurring on data line D00 about 78 nsec after DS0* was asserted (low). The spike takes the data line out of the TTL logical-zero voltage region to 1.68V, an undefined logic level. According to the VME Bus specification, data lines must be stable while the data strobe is asserted, so the DSO has captured a timing violation that might cause a system glitch. The timing violation caused the VBAT to generate a trigger pulse, which allowed the DSO to record the event.

Troubleshooting tools that are tailored to your system's bus can save you a lot of time and effort when you most need it—when your system is malfunctioning and holding up the rest of your project. Debugging complex systems based on multiple cards and a backplane is at best a worrisome task, and inadequate or improper tools simply compound your problems. If the cost makes it difficult for you to justify purchasing such tools, consider the amount of time you'll lose in searching for glitches and other bugs that your existing test equipment may not be able to detect. Today, when one of the most critical factors in product design is time to market, you probably don't need more justification than that. EDN

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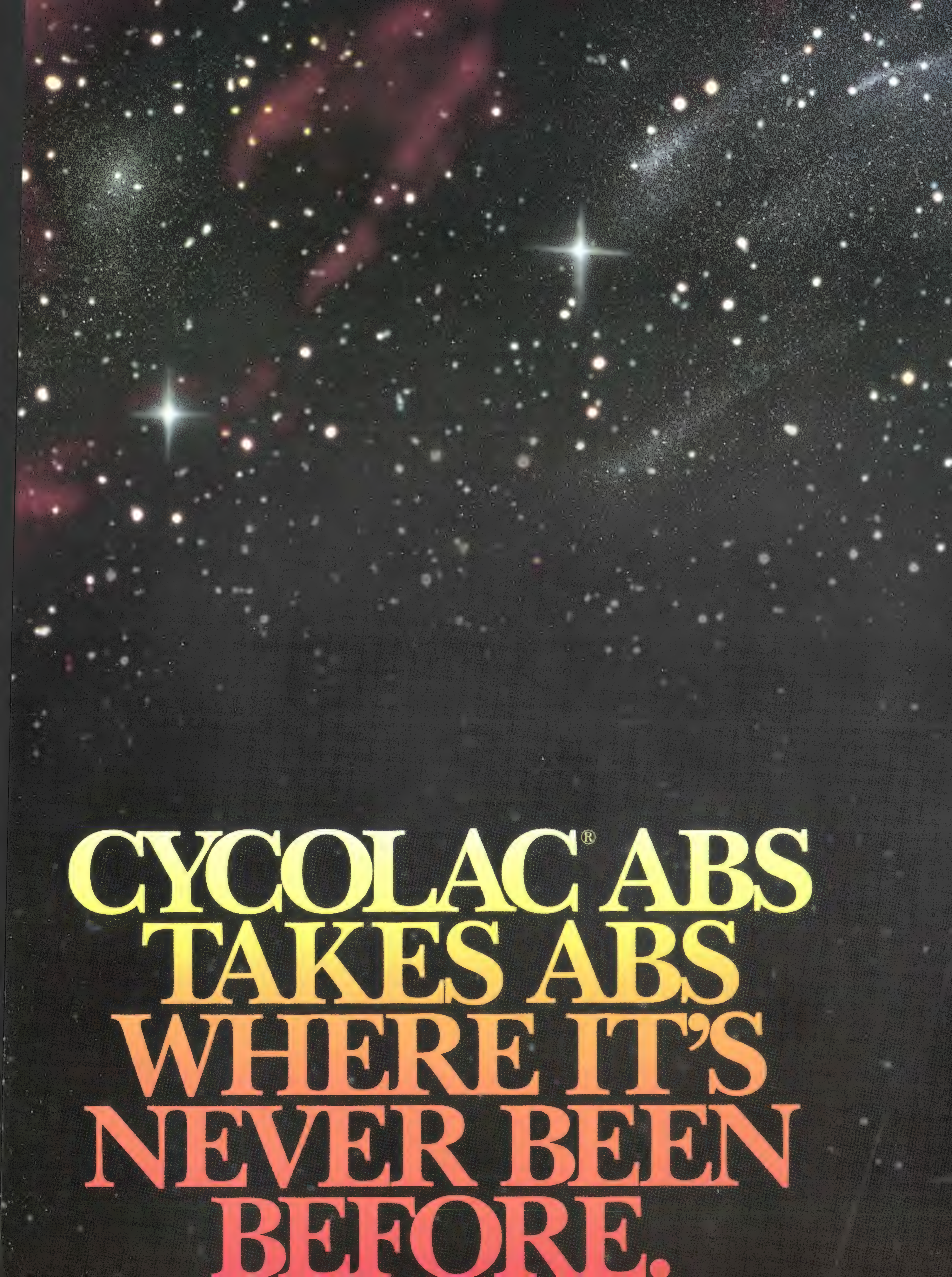
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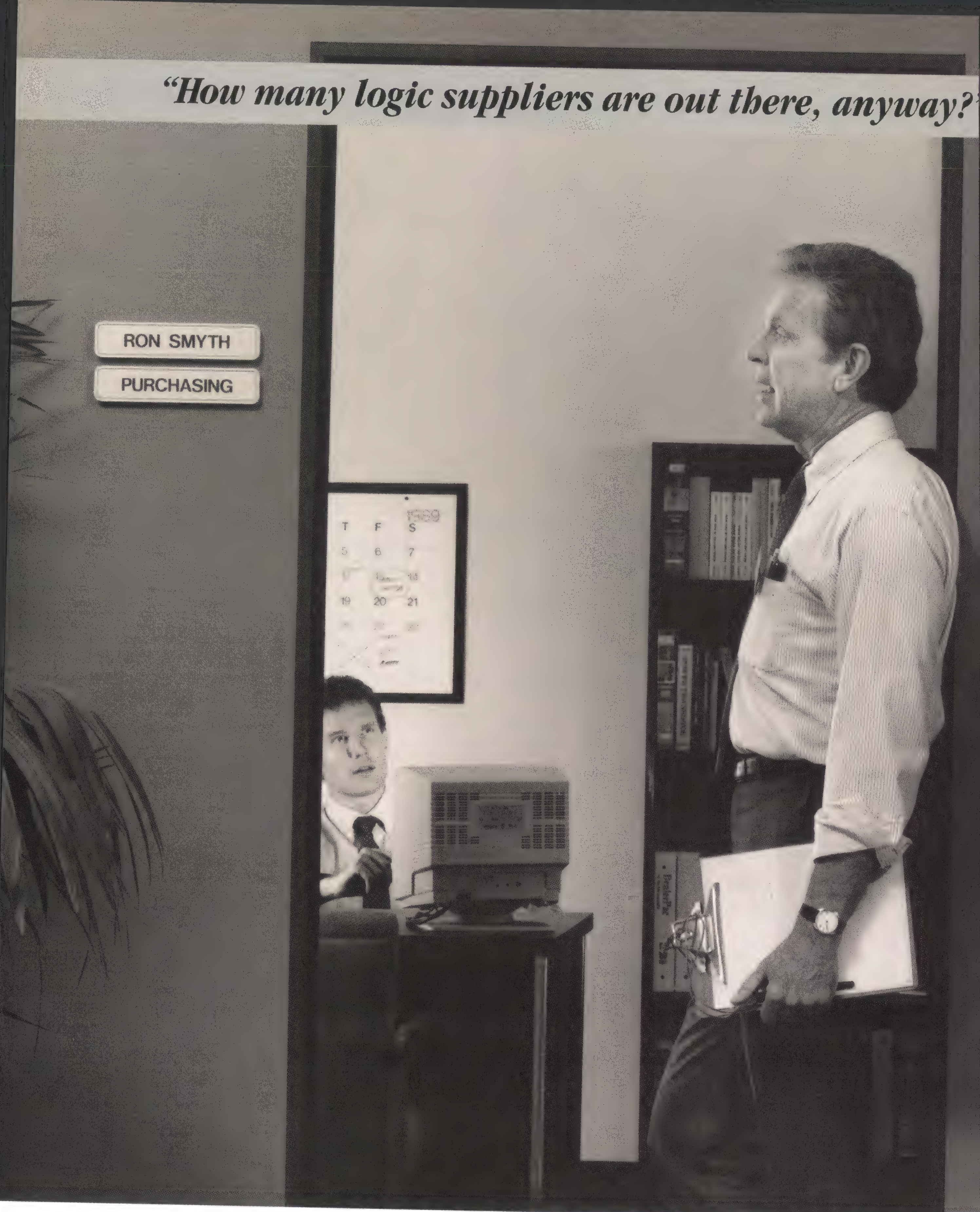
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CIRCLE NO 90

Buscon/89 West offers computer-bus update

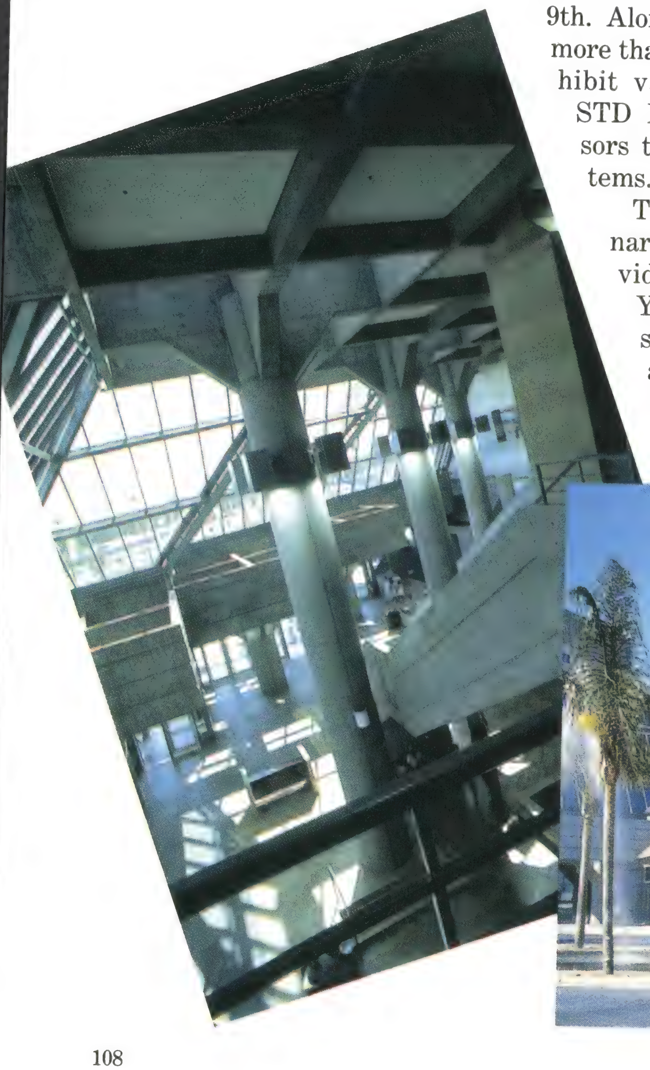
Cynthia Rettig,
Associate Editor

In addition to covering board-and system-level designs, Buscon/89 West will emphasize Unix and real-time development and run-time environments for a wide range of complex applications. The conference and show will be held at the Santa Clara, CA, Convention Center. The conference begins on Monday, February 6; the show opens on Tuesday, February 7 at 2:00 PM by invitation only and is open to all registrants on Wednesday and Thursday. Both the confernce and the show end on the 9th. Along with the conference, more than 150 companies will exhibit various products, from STD Bus and 16-bit processors to 32-bit and RISC systems.

The conference's seminars and sessions are divided into three tracks. You may stay within a single track or opt for a variety of meetings in different tracks.

Track 1, "Board-level Design," offers a tutorial on ASICs and a workshop on NuBus. Beginning on Tuesday, the sessions start with an introduction to buses that will cover terminology and basic concepts for those new to the field. At the session on the VXI Bus standard, speakers will explain various aspects of the new standard, including how to integrate it with its precursor, the VME Bus. Other sessions will cover new issues in popular architectures. A final session on Thursday will discuss the development of board- and system-level products that are suitable for harsh environments and/or military use.

Track 2, "System-level design," will present two seminars on backplane-bus design, both conducted by Dr Paul Borrill, a staff scientist at National Semiconductor. The first will give an overview of both the theoretical and practical aspects of the physical layer, including electrical performance, transmission-line theory, and drive problems. The second seminar will present specific examples of bus design, including the VME Bus, Multibus II, NuBus, and



BUSCON/89 WEST PROGRAM SCHEDULE

SEMINAR 10 — MONDAY, FEBRUARY 6 — 2:00 PM TO 5:00 PM NASA FACE-TO-FACE WITH THE INDUSTRY

		TRACK 1 BOARD-LEVEL DESIGN	TRACK 2 SYSTEM-LEVEL DESIGN	TRACK 3 REAL-TIME SOFTWARE	GENERAL SESSIONS
MONDAY, FEBRUARY 6	8:00 AM TO 12:00 PM	SEMINAR 11 ASIC TUTORIAL	SEMINAR 12 BACKPLANE BUS DESIGN I	SEMINAR 13 REAL-TIME SYSTEM DESIGN	
	1:00 PM TO 5:00 PM	SEMINAR 21 NUBUS WORKSHOP	SEMINAR 22 BACKPLANE BUS DESIGN II	SEMINAR 23 REAL-TIME SYSTEM DESIGN	
TUESDAY, FEBRUARY 7	9:00 AM TO 11:00 AM	SESSION 101 INTRODUCTION TO BUSES	SESSION 102 REAL-TIME GRAPHICS	SESSION 103 REAL-TIME KERNELS (8:00 AM TO 12:00 PM)	**SESSION 1000 BUSES MEET THE PRESS**
	2:00 PM TO 4:00 PM	SESSION 201 VXI INSTRUMENTATION BUS	SESSION 202 CONSIDERATIONS IN SYSTEM PACKAGING	SESSION 203 REAL-TIME DEVELOPMENT ENVIRONMENTS (1:00 PM TO 5:00 PM)	
WEDNESDAY, FEBRUARY 8	9:00 AM TO 11:00 AM	SESSION 301 NEW ISSUES IN VME BUS	SESSION 302 HIGH-PERFORMANCE ARCHITECTURES	SESSION 303 REAL-TIME ADA	
	11:00 AM TO 1:00 PM				**SESSION 2000 RISC ARCHITECTURES**
	2:00 PM TO 4:00 PM	SESSION 401 NEW ISSUES IN FUTURE BUS	SESSION 402 CRATE-TO-CRATE COMMUNICATIONS	SESSION 403 SOURCE-LEVEL DEBUGGING	
	6:00 PM TO 8:00 PM				**SESSION 3000 INTERNATIONAL BOARD-LEVEL SYMPOSIUM**
THURSDAY, FEBRUARY 9	9:00 AM TO 11:00 PM	SESSION 501 NEW ISSUES IN MULTIBUS II	SESSION 502 INDUSTRIAL NETWORKS	SESSION 503 REAL-TIME KERNELS (8:00 AM TO 12:00 PM)	
	11:00 AM TO 12 PM				**SESSION 4000 EDITORS FORUM**
	2:00 PM TO 4:00 PM	SESSION 601 DESIGNING FOR THE MILITARY	SESSION 602 SYSTEM INTEROPERABILITY	SESSION 603 REAL-TIME DEVELOPMENT ENVIRONMENTS (1:00 PM TO 5:00 PM)	

Fast Bus, as well as some proprietary designs.

Track 3, entitled "Real-time Software," will have a day-long seminar on Monday to cover the concepts, language, and methodologies of real-time system design. You can learn how to realistically evaluate the real-time needs of an application and how to solve basic problems in system design. The session on real-time software kernels will focus on those kernels that support popular μPs; it will provide detailed technical information on interrupt handling, scheduling, intertask communications, and synchronization facilities. In the session on source-level debugging, you can hear about the tools currently available for developing systems and application software in a variety of high-performance products—from Unix to real-time systems.

The conference will also sponsor some general sessions, which are complimentary. "Buses Meet the Press" will include a panel discussion of market trends, bus architectures, mergers, overseas competition, software issues, and bus-variations and compatibility problems. A forum on RISC architectures will cover marketing issues such as market presence, distribution, standards, and availability. There will also be a symposium on the role of distributors, where executives will talk about their companies' strategies. The "Editors' Forum" will give you an opportunity to meet and query editors from industry publications.

Buscon will also run a special seminar on Monday afternoon about NASA. The meeting will help you learn how to take advantage of NASA research by commercializing its products.

For more information on Buscon/West 89, you can contact Conference Management Corp (CMC), 200 Connecticut Ave, Norwalk, CT 06856. Phone (203) 852-0500.

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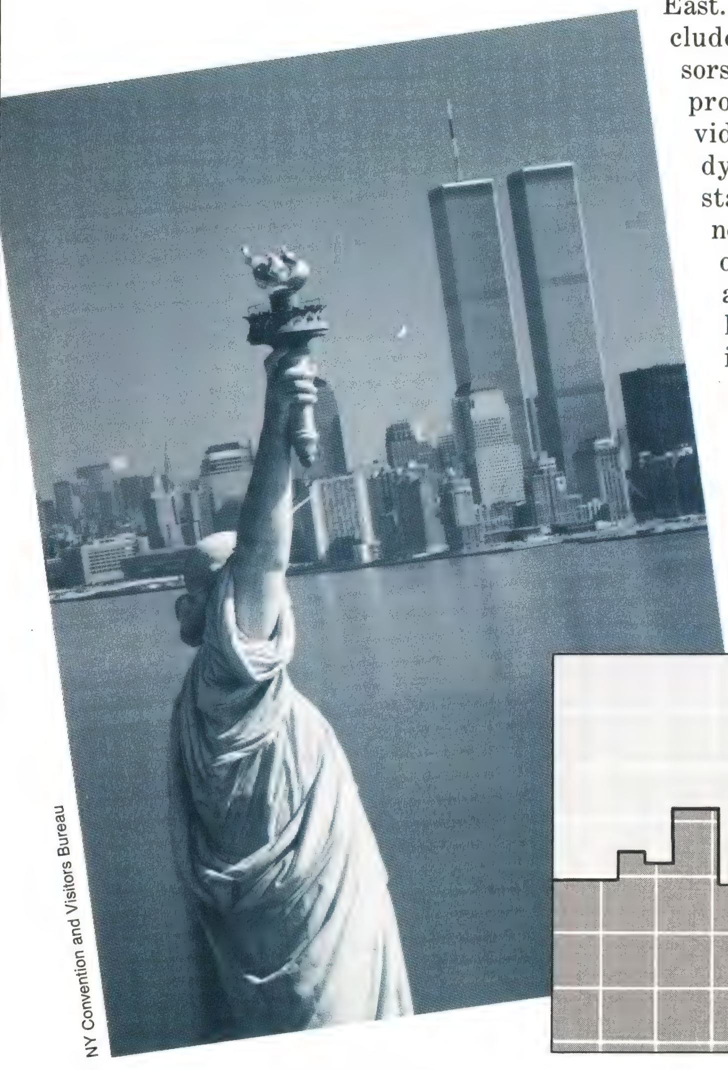
ISSCC '89 will present advances in ICs

Julie Anne Schofield,
Associate Editor

The continued rapid progress in integrated-circuit designs for a wide range of applications will be the focus of the 36th International Solid-State Circuits Conference, which will take place February 15 through 17 at the New York City Hilton Hotel.

Ninety papers will describe previously unpublished advances in IC technology, with contributions from the US, Europe, and the Far East. Topics will include microprocessors, floating-point processors, and video processors; dynamic RAM, static RAM, and nonvolatile memories; imagers and sensors; high-speed logic; and telecommunications, datacommunications, and data-converter circuits.



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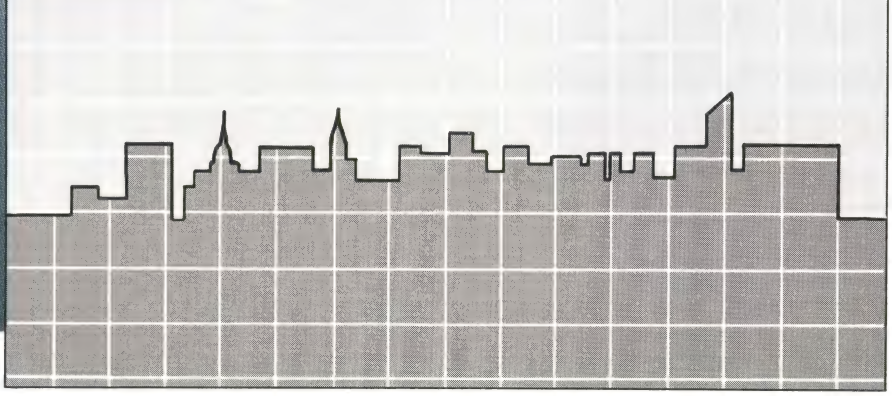
Papers in **session 1,** for instance, will cover data converters, including an 8-bit, 40-MHz CMOS subranging ADC with pipelined wideband S/H and a 13-bit, 160-kHz differential ADC. **Session 2** will describe high-speed static RAMs, including a 512k-bit, 5-nsec BiCMOS RAM with a 150-psec logic gate array and a 9-nsec, 1M-bit CMOS static RAM.

Floating-point processors of various speeds and capabilities will be discussed in **session 3.** And a pipelined RISC CPU that contains a 1k-bit I-cache, a 2k-bit D-cache, translation buffers, and a 64-bit external interface will be presented in **session 7.** In **session 9,** papers will describe merged CMOS/bipolar current switch logic and a single-ended, BiCMOS digital sense circuit.

Session 12 will include eight papers on digital video and image processors. Topics will include a digital-signal-processing chip for 1-chip color image sensors, a real-time image-processing chip set, and a 50-nsec video-signal processor. Papers presented in **session 17** will describe telecommunication ICs, including a single-chip BiCMOS telephone set and an ANSI-standard ISDN transceiver chip set.

The conception and evolution of digital audio will be the topic of the keynote address, which will be delivered by Dr



ISSCC 89

Day	Time	PROMENADE 2nd FLOOR	GRAND BALLROOM WEST	GRAND BALLROOM EAST	TRAINON BALLROOM	MERCURY BALLROOM	SUTTON NORTH & CTR.	NASSAU SUITE	GRAMERCY A–B
TUE FEB 14	4:00 PM TO 8:00 PM	REGISTRATION	—	—	—	—	—	—	—
WEDNESDAY, FEBRUARY 15	8:00 AM TO 4:00 PM	REGISTRATION	—	—	—	—	—	—	—
	9:00 AM	—	SESSION 1* DATA CONVERTERS	SESSION 2 HIGH-SPEED SRAMs	SESSION 3 FLOATING-POINT PROCESSORS	—	—	—	*TV THEATER
	LUNCH	—	—	—	—	—	—	—	—
	1:30 PM	—	SESSION 4 FORMAL OPENING		—	—	—	—	—
		—	SESSION 5 KEYNOTE ADDRESS		—	—	—	—	—
	3:30 PM	—	SESSION 6* AMPLIFIERS	SESSION 7 MICRO-PROCESSORS	SESSION 8 IMAGERS AND SENSORS	—	—	—	*TV THEATER
	6:00 PM TO 7:00 PM	—	—	—	—	—	—	AUTHOR INTERVIEWS	—
		—	INFORMAL DISCUSSION SESSIONS					—	—
	8:00 PM	—	WE 1 DESIGN OF 100 MIPS PROCESSORS	WE 2 DESIGN CHALLENGES FOR HIGH-SPEED HIGH-DENSITY SRAMs	WE 3 PRACTICAL LIMITS OF A/D AND D/A CONVERSION	WE 4 COMPETING TECH FOR NONVOLATILE APPLICATION	WE 5 FUTURE OF GENERAL-PURPOSE DIGITAL SIGNAL PROCESSORS	—	—
THURSDAY, FEBRUARY 16	8:00 AM TO 4:00 PM	REGISTRATION	—	—	—	—	—	—	—
	9:00 AM	—	SESSION 9* HIGH-SPEED DIGITAL BiCMOS ICs	SESSION 10 NONVOLATILE MEMORIES	SESSION 11 DATA COMMUNICATION ICs	—	—	—	*TV THEATER
	LUNCH	—	—	—	—	—	—	—	—
	1:30 PM	—	SESSION 12* DIGITAL VIDEO AND IMAGE PROCESSING	SESSION 13 GATE ARRAYS	SESSION 14 ANALOG PROCESSORS	—	—	—	*TV THEATER
	6:00 PM TO 7:00 PM	—	—	—	—	—	—	AUTHOR INTERVIEWS	—
		—	INFORMAL DISCUSSION SESSIONS					—	—
	8:00 PM	—	THE 6 NEW DIRECTIONS IN PROGRAMMABLE LOGIC	THE 7 ULSI TECHNOLOGY DRIVERS: DRAM SRAM OR ASIC?	THE 8 ANALOG STANDARD CELLS — A POWERFUL TOOL WHOSE TIME HAS COME?	THE 9 WILL DIGITAL CIRCUITS EMBRACE BiCMOS?	THE 10 COMPUTER NETWORKING IN THE OFFICE/ BUSINESS ENVIRONMENT	—	—
FRIDAY, FEBRUARY 17	8:00 AM TO 11:00 AM	REGISTRATION	—	—	—	—	—	—	—
	9:00 AM	—	SESSION 15* HIGH-SPEED DIGITAL CIRCUITS	SESSION 16 DYNAMIC RAMs	SESSION 17 TELECOM ICs	—	—	—	*TV THEATER
	12:30 PM TO 1:30 PM	—	—	—	—	—	—	AUTHOR INTERVIEWS	—

*ASTERISKS INDICATE SESSIONS ALSO SHOWN IN TV THEATER

Heitaro Nakajima of Sony Corp. Dr Nakajima will discuss the factors that led to the development of this highly successful technology and the evolution of digital audio from consumer to nonconsumer applications.

According to Dr Nakajima, this evolution is the opposite of that of most technologies, which have evolved from industrial or military applications into consumer applications. He believes that this evolution has been possible because a consumer application ensures a large market, thus making it possible to develop sophisticated VLSI chips and other key components and supply them at moderate cost. The availability of these components, in turn, facilitates the development of a variety of systems that would not otherwise be economic, Dr Nakajima maintains.

Evening informal discussions

In addition to the technical sessions, the ISSCC will include 10 informal discussion sessions on Wednesday and Thursday evenings. More than 70 international authorities will debate 100-plus-MIPS processors; high-speed, high-density static RAMs; the limits of A/D and D/A conversion; nonvolatile memory; the future of general-purpose DSPs; new directions in programmable logic; ULSI technology drivers; analog standard cell design; BiCMOS for digital applications; and computer networking.

All registrants will receive a copy of the annual *Digest of Technical Papers*. The book features introductory overviews of the contributed papers and editorials summarizing the proceedings of the evening sessions. Additional copies of the book can be purchased at the conference. Registration fees at the door are $200 for IEEE members and $220 for nonmembers. EDN

Article Interest Quotient
(Circle One)
High 506 Medium 507 Low 508

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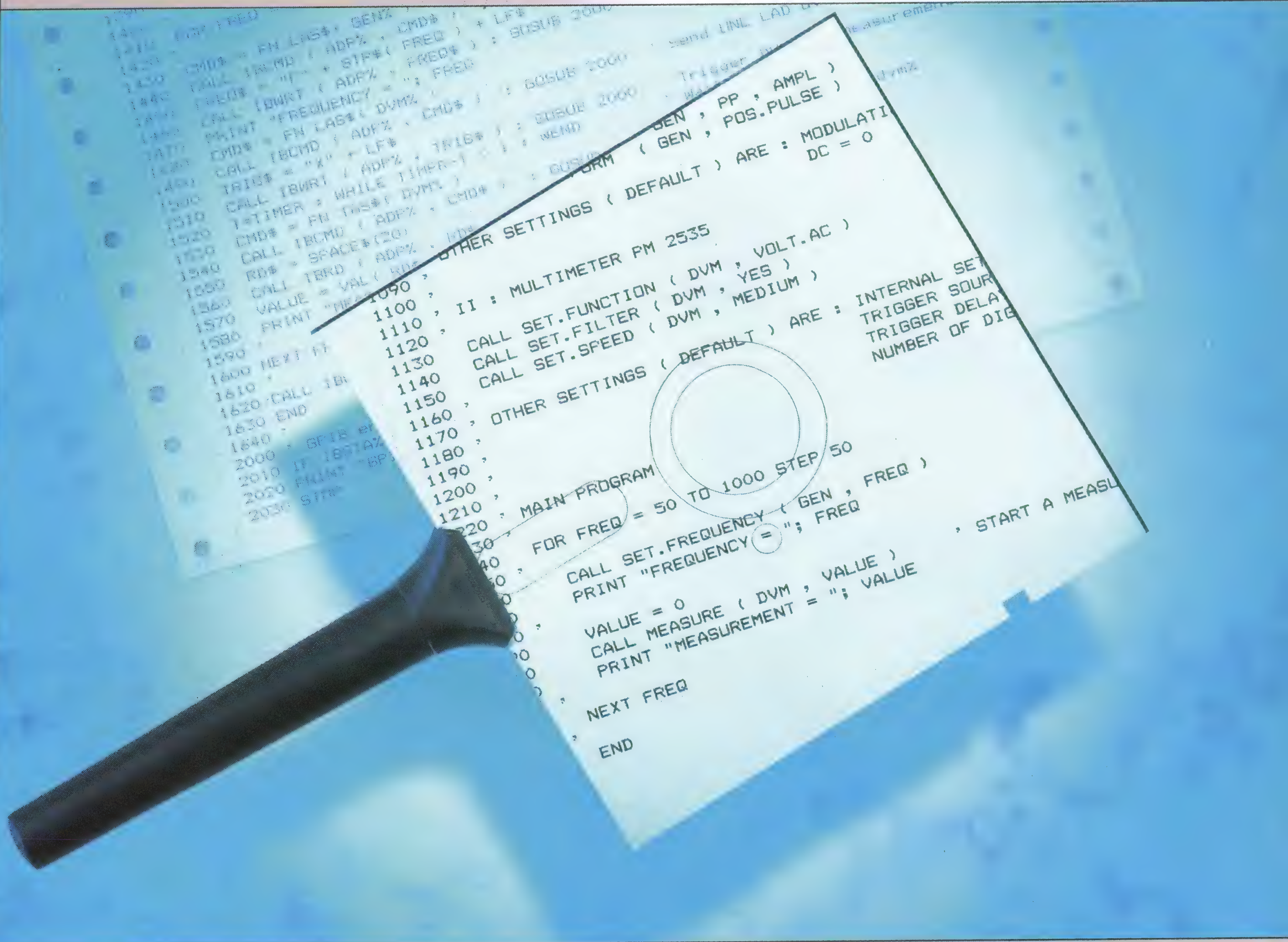

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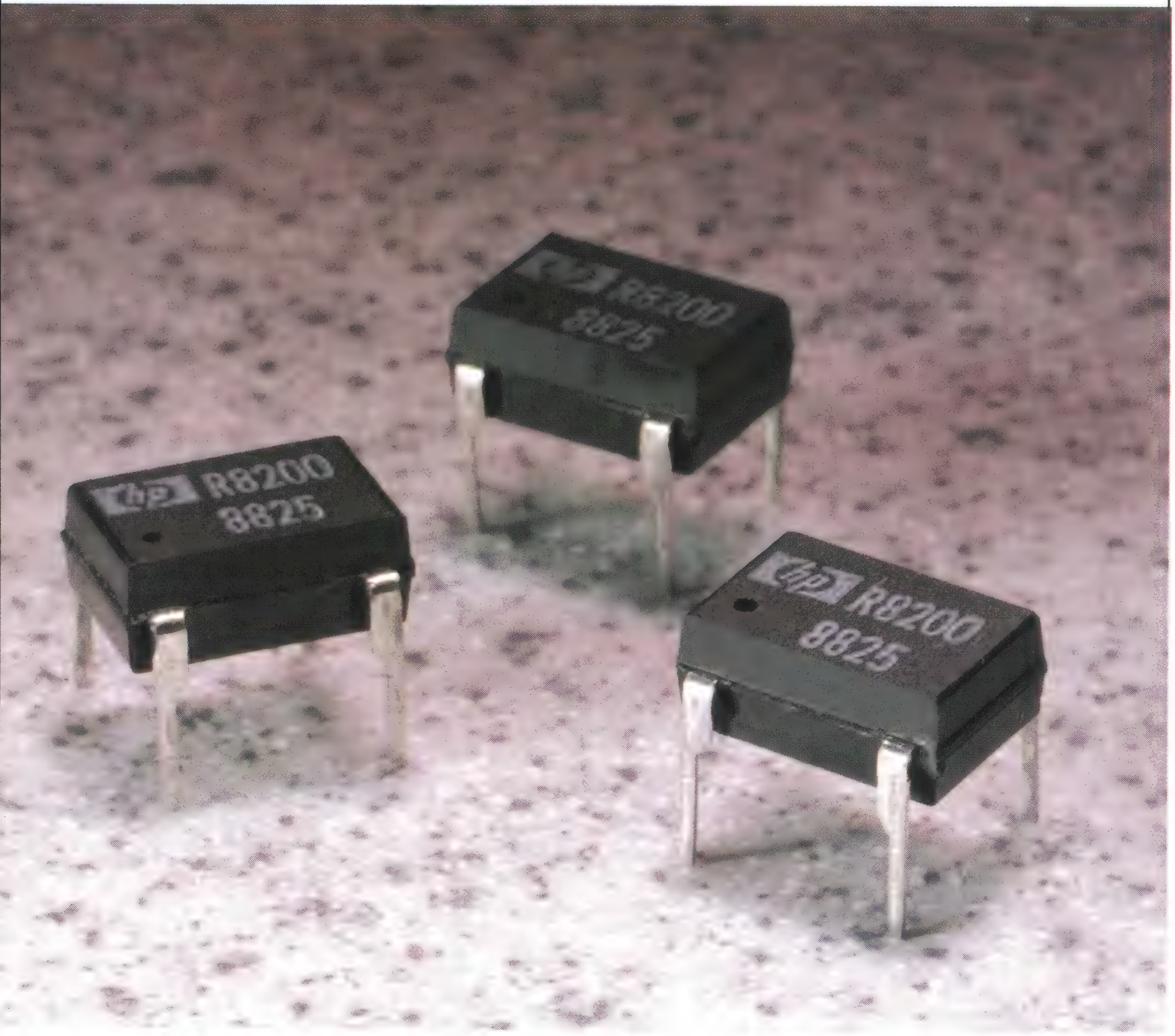

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Thumb-actuated, cursor-positioning device provides 2-D axis control in a small space

Though it provides functions similar to that of a trackball or mouse, the Isopoint cursor-positioning device requires much less room than these alternative products and, when placed just below a conventional keyboard, allows touch typists to keep their hands near the home row. Because of its small size, the Isopoint allows you to incorporate 2-D cursor control in small products such as laptop computers or instruments that previously accommodated only cursor-control keys because of limited keyboard area or front-panel space.

The purchase of an early Apple Macintosh computer inspired Craig Culver, president of Culver Research (Woodside, CA), to develop a cursor-control device that he felt would be superior to the Macintosh mouse. Culver wanted to manipulate the cursor on the computer's screen without moving his hands away from the keyboard's home position. This goal required the device to be small enough to mesh with the standard Qwerty keyboard layout. The final configuration is the

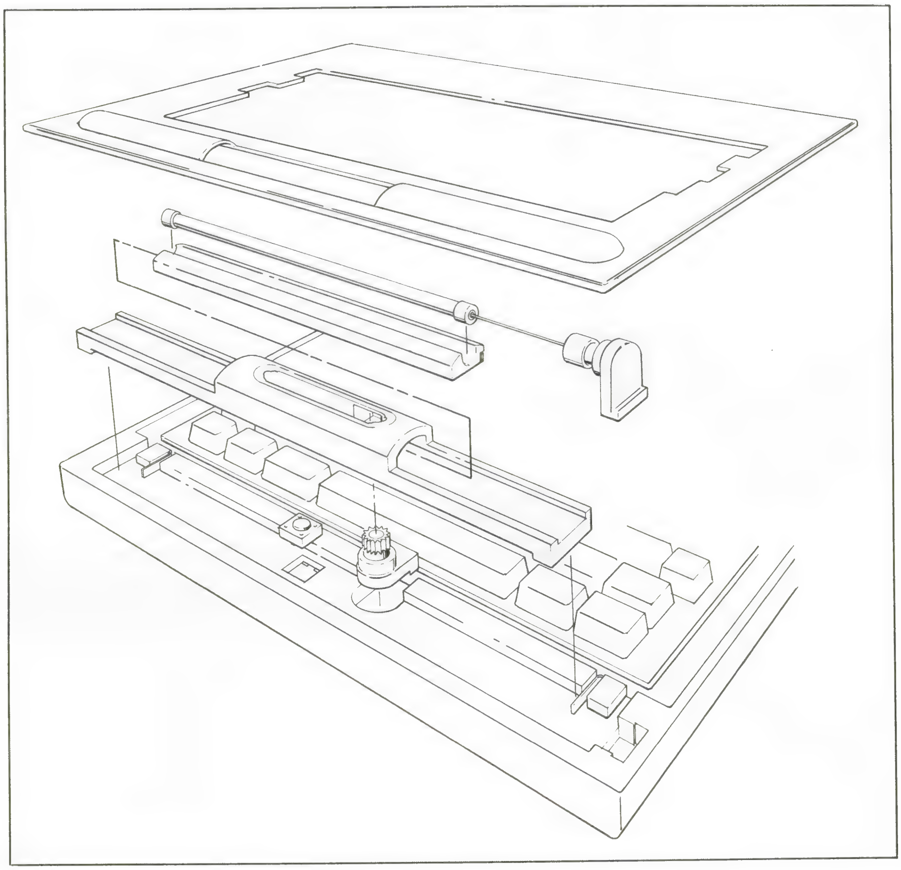


***Fig 1—A roller coupled to an optical shaft encoder** in the Isopoint provides one control axis, and a sliding cradle coupled to a second encoder through a rack-and-pinion gear train provides the other control axis.*

***Nestled just below the space bar** on this personal computer keyboard, the Isopoint control allows touch typists to move a cursor around on the screen without moving their hands from the home position.*

fortieth design iteration developed by Culver over a period of four years and is covered by three patents.

The Isopoint's design centers around a thin roller coupled to a miniature rotary-shaft encoder that provides one axis of control (**Fig 1**). You rotate the roller with the friction from a thumb or finger to produce a quadrature-output signal from the encoder. The roller rests in a sliding cradle that drives a second encoder through a rack-and-pinion gear train. Thus, you drive the second axis by sliding the cradle back and forth, using the same thumb or finger to turn the roller. The cradle rests on a switch so you can replicate the click of a mouse button simply by pressing down on the roller assembly.

The two optical encoders are key to the control's small size. Custom built by Alps, the Isopoint's encoders are about half the size of encoders the company fabricates for its mouse and trackball products. Through a license from Culver Research, Alps offers the Isopoint as an optional device for its line of custom keyboards. The company estimates that the Isopoint in OEM quantities would add no more than $30 to the cost of a keyboard. Alps also plans to offer the Isopoint as a stand-alone product with an RS-232C interface.—***Steven H Leibson***

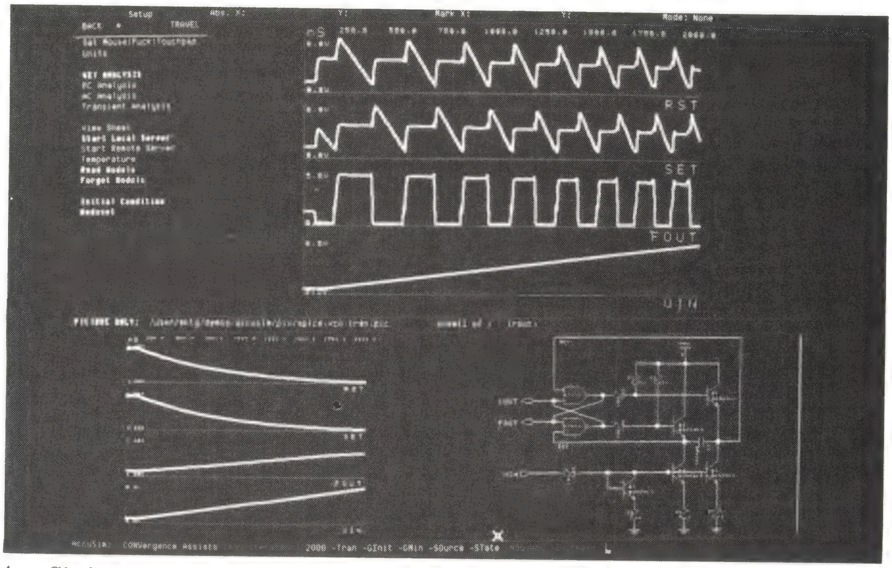
Alps Electric (USA) Inc, 3553 N First St, San Jose, CA 95134. Phone (408) 432-6000. FAX 408-432-6035.

Circle No 732

Analog simulation package offers enhanced convergence and large library

When simulating circuits, the analog designer often faces the problem of simulations that don't converge. By providing enhanced convergence performance, AccuSim, an analog simulation package, allows you to concentrate on circuit design rather than on how to make the simulation converge.

The vendor has improved the basic simulator's ability to converge on a solution compared with the performance of the standard Spice 2G.6. Among these proprietary improvements is a timestep control algorithm, which, the vendor claims, will work on circuits having more than 5000 transistors. Although many simulation packages have proprietary enhancements to help improve convergence, AccuSim goes a step further. For cases where the standard simulation doesn't converge, it provides you with five interactive convergence-assistance algorithms.



***AccuSim's timestep control algorithm (upper right) correctly simulates** the voltage-controlled oscillator circuit shown in the lower right. Simulating this circuit on a standard Spice 2G.6 simulator (lower left), the simulator drifts around the circuit's dc bias point without detecting the onset of oscillation.*

These five algorithms are based on the idea that an iterative-solution method has difficulty following abrupt changes, such as those at power-up. In such a situation, the likelihood of convergence is much greater if the program is able to compute these abrupt changes in small steps. Thus the simulation package allows you to enable or disable any of the five algorithms and control the number of convergence-assistance iterations performed by the simulator.

In addition to improving convergence performance, having tools like the interactive convergence-assistance algorithms at your disposal can boost productivity. And, having a library of models for the components you're using can also increase productivity. You'd also like large libraries, but you need more than this: You need open models that you can modify. AccuLib, which is being released with AccuSim, addresses this need for a model library. The initial release will contain open models for 1800 parts, including bipolar transistors, diodes, JFETs, MOSFETs, ICs, and power supplies. The vendor plans a library growth rate of 600 parts/year, provided in quarterly updates and emphasizing user-requested components.

AccuSim is available as a completely integrated electronic-design automation package when you purchase the Analog Station. The Analog Station package includes software for schematic capture, documentation, and AccuSim and Monte Carlo Analysis; AccuLib is available as an option.

Because Analog Station uses the vendor's standard databases and can use the vendor's design network, analog designers can share access to the same database that digital logic engineers, layout designers, and mechanical engineers use. The vendor also plans to address other areas, such as developing a magnetics library, providing tools to make model development easier for the analog designer, and adding temperature stress analysis and mixed-mode simulation.

The cost of adding AccuSim to an existing Idea Series workstation is $22,000; AccuLib, as a site subscription with quarterly updates, also sells for $22,000. Both will be available in April 1989. The price of a Monte Carlo upgrade is $7500, and it's available now. Pricing for a full Analog Station, including Apollo DN 3010 hardware, starts at $31,900, and it's scheduled for release in the third quarter of 1989.—***Doug Conner***

Mentor Graphics Corp, 8500 SW Creekside Pl, Beaverton, OR 97005. Phone (503) 626-7000.

Circle No 730

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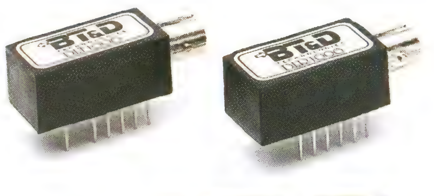

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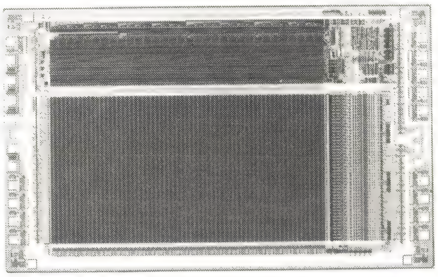
CIRCLE NO 81

Content-addressable memory yields address when given data

The Am99C10 memory device works in reverse; you give it data, and it gives you the address. Content Addressable Memory (CAM) is suited to applications that require frequent searches for specific information. For example, an Ethernet bridge controller must determine if an incoming address designates a member of its network and respond accordingly. With conventional memory, you have to read and compare each location in an address list to determine if a match exists; a CAM finds the answer in one memory cycle.

The Am99C10 CAM is organized as 256 16- or 48-bit words and includes a mask register. When you present data to the CAM, it performs 256 simultaneous comparisons between the memory and the data word. You can use the register to selectively mask any or all bits from the comparison process. If the CAM finds a match, it sets a flag and identifies the address of the matching word. If a match doesn't exist, the CAM clears the flag and generates the lowest empty address. In the event that the CAM finds multiple matches, it provides the lowest matched address.

To identify all the matches, you must utilize two additional bits of memory located at each cell—the empty bit and the skip bit. Both bits can disable a match for their word. The empty bit indicates that a memory cell is available for new data. The skip bit lets you identify all matching words other than the word with the lowest address. To locate the multiple matches, you set either the skip bit or the empty bit for each matching word and repeat this match operation until the CAM stops issuing a match signal.



***The Am99C10 memory device works in reverse;** when you supply the data word, it generates the word's address in memory.*

The CAM lets you individually write the skip and empty bits of each word. You can either clear or set all the empty or skip bits simultaneously. Further, the device automatically clears the two bits when you write new data to a memory cell.

Featuring a 16-bit-wide data bus, the CAM requires three memory cycles to read or write a 48-bit data word. The control register, which reads commands, and the status register, which writes data, are both 16 bits wide. They make it possible for you to execute commands in a single 100-nsec cycle.

The CAM is a TTL-compatible, CMOS device. It operates at 5V and draws a maximum of 715 mW. Priced at $42.50 (100), the device comes in a 28-pin ceramic or plastic DIP, or in a 32-pin plastic leaded chip carrier.— **Richard A Quinnell**

Advanced Micro Devices Inc, 901 Thompson Pl, Sunnyvale, CA 94088. Phone (408) 732-2400.

Circle No 734

IEEE-488 bus extender drives coaxial and fiber-optic cables

The Model 4889 Roadrunner extender for IEEE-488 bus systems minimizes the cable-length/data-rate tradeoff. Whether you expand the link 500m using coaxial cable or as much as 2000m using fiber-optic cable, the Roadrunner maintains a 300k-byte/sec data transfer rate.

Model 4889 is completely transparent to all IEEE-488, GPIB, HP IB, and HP CS-80 commands and data; the device's built-in intelligence eliminates the need for special programming. The extender supports all IEEE-488 bus functions, including Pass-Control and Parallel-Poll commands.

The Roadrunner includes both a coaxial driver and receiver, and an optical transmitter and receiver. The coaxial driver is designed for use with Belden 9248 or equivalent double-shielded, 75Ω cable. The optical path uses 120-μm core/140-μm clad fibers and SMA connectors. The fiber-optic link operates at a 820-nm wavelength. You can check both ports using the extender's built-in loopback test. In addition, the unit has a built-in error-control protocol that guarantees error-free data transfers.

In the event of a link failure, the Roadrunner's truncation feature frees the local bus and the bus controller, thus preventing the rest of the system from crashing. If the bus controller times-out, the unit holds the local bus until the link is restored. You can operate the 4889 in either the automatic or the software-commanded truncation mode.

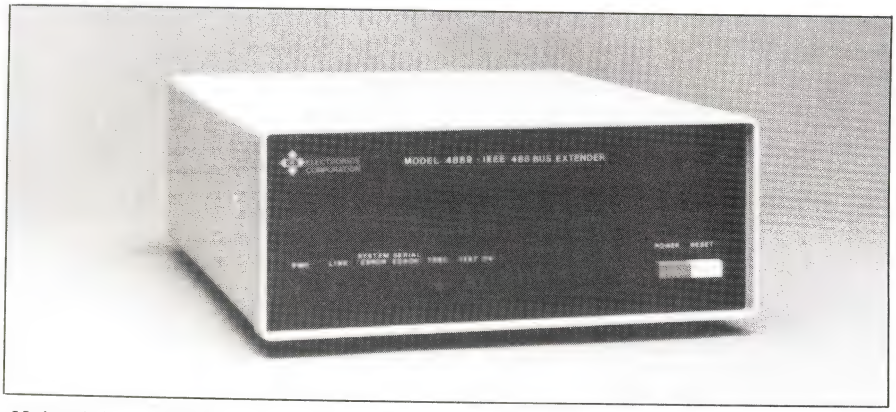
Several front-panel indicators display the extender's status and link performance. The indicators light when a link is established, flash when a serial transmission error occurs, and show when two bus controllers are present or if the link has been truncated. Another indicator lights if the unit is in test mode.

Like any bus extender, the Roadrunner impairs the communication link's response time. The delay in transfer response from a remote device ranges from 8 to 16 μsec, and the parallel-poll response delay is 16 to 36 μsec.

The Model 4889 extender operates at 115V ac, 48-62 Hz and consumes 28W. Other operating voltages, including 100, 200, and 230V ac, are optional. The Roadrunner costs $1695.—***Richard A Quinnell***

ICS Electronics Corp, 2185 Old Oakland Rd, San Jose, CA 95131. Phone (408) 432-9009.

Circle No 733



Maintaining a 300k-byte/sec data transfer rate, *the IEEE-488 bus extender handles distances as great as 500m using coaxial cable or 2000m using fiber-optic cable.*

Computer workstation and server family accommodates multiple SPARC processors

The Series4/600 computer workstations and Series4/800 file/compute servers employ SPARC (scalable processor architecture) μPs and execute programs written for Sun 4 computers from Sun Microsystems (Mountain View, CA), including Sun's own diagnostic programs. However, unlike the Sun 4 machines, the Series4 computers accommodate as many as four SPARC CPUs, thus enhancing the computers' ability to execute multiple tasks quickly.

All models in the Series4 family include at least 16M bytes of RAM, a 7-slot VME Bus card cage, an Ethernet LAN controller, two RS-423A/RS-232C ports, a SCSI port for connecting to mass-storage devices, the SunOS Unix operating system, the X Window System and X Window Manager for multiple-window displays, and a C language compiler. The computers support coarse-grained multiprocessing, splitting work at the Unix task or application-program level. This division of labor not only allows you to run existing Sun 4 programs without recompilation, but it also exactly matches the X Window System's paradigm of client and server processes.

The company markets members of the workstation and server families with one to four SPARC CPUs. Each Series4 CPU card incorporates a Fujitsu SF9010IU SPARC μP and Weitek floating-point chips. The CPU boards reside on the company's proprietary, 64-bit Kbus, which operates at 128M bytes/sec. You add μPs to the computers by simply plugging additional CPU boards into the computer's 7-slot Kbus backplane.

You can plug as many as four CPU boards *into Solbourne Computer's SPARC-based Series4 computers; these computers can execute all programs written for Sun Microsystems' Sun 4 workstation family.*

Series4/600 workstations occupy a single cabinet and can accommodate one hard-disk drive with as much as 1.3G bytes of storage. The Series4/800 servers add a second cabinet, which can hold as many as three high-speed, SMD, hard-disk drives that add as much as 3.3G bytes of storage. Each Series4 cabinet measures 18×30×22 in., allowing the machines to fit comfortably next to a desk.

A 2-processor Series4/602 with 16M bytes of RAM, a 327M-byte hard disk, and a 150M-byte cartridge-tape drive sells for $51,400. The single-processor Series4/801 server equipped with 32M bytes of RAM and two SMD drives, providing 1.66G bytes of storage costs $75,400. All of the company's computers carry a 1-year warranty.

—Steven H Leibson

Solbourne Computer Inc, 2190 Miller Dr, Longmont, CO 80501. Phone (303) 772-3400. FAX 303-772-3646.

Circle No 731

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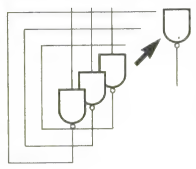

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EDN SPECIAL REPORT

Core μPs

Peter Harold, *European Editor*

Submicron CMOS technology now allows you to design ASICs that contain around 200,000 equivalent gates on a single chip. But what can you do with such a high level of integration? For one thing, you can now integrate a core μP onto the chip, yet still have enough silicon area left over to implement complex memory and peripheral logic. As a result, you can often collapse a complete pc-board μP system into a single IC, accruing not only savings in space and power consumption, but (at least for large production quantities) savings in unit cost as well. Another option is to combine a 32-bit RISC processor with an on-chip floating-point coprocessor and a cache-memory subsystem to produce a single-chip μP that can outperform a minicomputer.

A core μP only contains those logic elements needed to execute its instruction set, such as microcode ROM, microcode state machines, a program counter, special-function registers, ALU, and interrupt logic. Peripheral logic, like the TTL-compatible address-bus buffers and bidirectional data-bus buffers, which a standard μP uses to communicate with off-chip memory and peripherals, are not in the core. If you're able to put a complete system including memory and peripherals, on a single chip, you won't need these bus buffers. Some microcontroller cores, however, retain some additional functions, such as a watchdog timer, or an inter-IC-bus serial port. Core μPs began hitting the market about two years ago, and now many manufacturers offer them in their ASIC design libraries.

To date, designers have used core μPs primarily to make enhanced microcontrollers. Most of the enhanced microcontrollers currently on the market use standard-cell ASIC technology to marry a core μP to an appropriate set of peripheral cells. Microcontroller vendors can thus provide standard parts, which only require the addition of the users' program codes to be ready for specific applica-

Smaller process geometries let you integrate enough memory and peripherals alongside a core μP to make complete systems on silicon a practical proposition. And you're no longer limited to 8 bits—16-bit CISC and 32-bit RISC core μPs are now available for designing high-performance microcontrollers or VAX-level μPs.

Using a palette that includes the basic logic elements of a core μP, you can design highly integrated circuits by choosing peripherals and memory to match. (Photo courtesy SGS-Thomson Microelectronics)

Integrating a core μP into an ASIC is a costly and time-consuming task. Don't undertake it unless you've got a good reason for doing so.

tions, such as telecommunications, automotive-engine management, or industrial control. Indeed, given the plethora of these enhanced microcontrollers available, you should think seriously about whether you want to embark on your own costly microcontroller design.

Enhanced microcontrollers often cost only a few dollars. If a particular enhanced device doesn't have exactly the functions you require, then buying one that has slightly more functions than you actually need, or adding one or two standard peripheral chips to one that doesn't have quite enough of what you want, could prove to be a cheaper and easier solution than designing your own ASIC. Furthermore, because many of these enhanced microcontrollers are based on industry-standard microcontrollers, such as the 80C51, cheap development systems and emulators are available for developing and debugging software. In many cases, an IBM PC with an add-on emulator is all you need. So consider your options—don't design in a core μP unless you've got a compelling reason to do so.

That compelling reason may simply involve real-estate considerations: Perhaps you simply don't have the space to accommodate more than a 1-chip solution, and the application can't be satisfied by any available single-chip microcontroller. Or you may want to prevent the copying of your design by having a totally proprietary solution. On the other hand, you may want to design your own core μP simply because you need to modify the way in which a particular μP operates; you might have to change the interrupt logic to achieve a high-speed prioritized interrupt response, or you might want to add instructions to the device's instruction set. With an off-the-shelf μP or microcontroller, you're restricted to the way the device's original designer thought it should be done.

Core μPs add design flexibility

Flexibility is in fact one of the major advantages of a core μP in comparison to its standard-part equivalent; a core isn't limited by pin-count restrictions. In many cases, the I/O logic between the package pins and a standard part's internal core prevents you from getting close enough to the core to use external logic to modify it.

Consider the logic provided on each bidirectional I/O pin on the G port of National Semiconductor Corp's and Sierra Semiconductor Corp's COP800 core cell. **Fig 1** compares this logic to that in the COP820C microcontroller with which the COP800 core is functionally compatible. In the COP820C standard product **(1a),** the G port logic interfaces to a single device pin via a 3-state buffer; in the core cell, on the other hand, the logic gives you 4 separate I/O signals **(1b).** By adding the pad cell shown in **Fig 1b,** you can generate a single

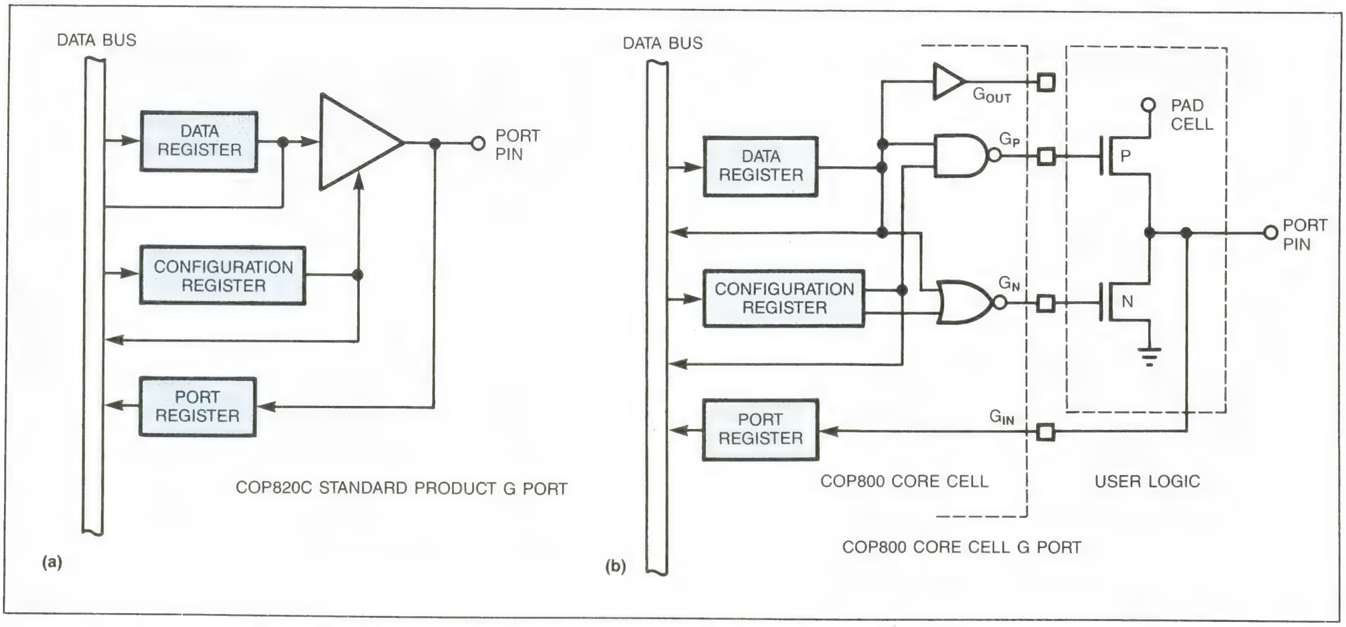


Fig 1—The I/O logic on the G-port *of Sierra Semiconductor's COP800 μP core* ***(b)*** *gives you greater flexibility than that on the COP820C standard part* ***(a).*** *Connected to the pad cell as shown, it mimics the standard part, but it can also provide separate input and output lines, and push-pull drive to other on-chip logic.*

bidirectional I/O line similar to that of the COP820C. However, because the core cell gives you access to all four I/O signals, you could just as easily use the logic to provide separate input and output lines rather than a single bidirectional line.

Another advantage to using a core μP is that it allows you to add memory and/or peripheral devices directly to the processor's data and address bus. Standard microcontrollers aren't really designed for off-chip expansion: Their address and data buses are often hidden behind I/O port logic, which frequently limits the speed of off-chip accesses and restricts the processor's addressing capabilities. On the other hand, within the bounds imposed by bus-loading and die-size considerations, a core μP allows the connection of several user-defined memory or peripheral cells directly to the address and data bus of the processor. This adaptability lets you implement the memory and peripheral architectures that can optimize system performance.

Choose between hard and soft cores

The degree to which you can modify the functions of a microprocessor core depends very much on whether it's available as a hard core or a soft core. A hard core is usually an exact layout copy of the core used in standard μP part. Because it's defined at the layout level, the performance of a hard core is very well specified, and you can be quite sure how it will perform when integrated into your ASIC design. Also, because a hard core is almost exactly equivalent to its corresponding standard μPs, you can emulate any given design by using the standard part. Still, if you want to modify the cores' functions, a hard core's full definition at the layout level is its greatest drawback. Other than adding additional logic around the periphery of the core—to modify interrupt handling, for example—major functional changes are impossible.

A major criticism often leveled at hard cores is that they can't take advantage of improved silicon processing because they are frozen in the process technology in which the standard parts were produced. Unless the standard part gets redesigned in a smaller process geometry, you can't obtain the core in the smaller geometry, so many hard cores must be fabricated in a 2- or 3-μm process. As a result, the area occupied by the core cell, and by its associated memory and peripheral cells (which must be fabricated in the same process), may seriously limit the functions possible on a reasonable size die.

Manufacturers define soft cores at a software level

Building systems on silicon *may not be as easy as this photograph from VLSI Technology suggests. However, the design tools are available that allow you to produce semicustom microcontrollers or high-performance RISC machines on a single chip.*

within a standard-cell library rather than at a layout level. In fact, soft cores are macrocells (often referred to by ASIC vendors as megacells or supercells because of their complexity). Because they are composed of a number of less complex building blocks from the ASIC library, it's possible to modify the soft cores' functions by adding and/or deleting blocks.

Seattle Silicon Corp has implemented an ASIC that contains a functional model of a Z80 μP, enhanced by a 256×16-bit stack RAM, a hardware multiplier, and improved register access. The core maintains object-code compatibility with the standard Z80 μP. In addition, because the device is fabricated in a 1.5-μm process, it operates at a clock rate of 20 MHz (a standard Z80's typical clock rate is 4 MHz).

Keep in mind that some ASIC vendors won't accept responsibility for the correct operation of core cells that you've modified. That won't cause you too many simulation problems, provided you can still generate a gate-level simulator for the modified core. But finding a way to emulate the modified part in hardware may not be so easy.

Definition at the software level also makes it easier for an ASIC vendor to upgrade a soft-core μP to new process geometries. Thus, although the core might oc-

Hard-core μPs achieve maximum silicon utilization, but soft cores allow you to modify a processor's functions.

cupy two-thirds of an acceptable die size in a 1.5-μm process, if the ASIC vendor offers the same cell in a 1-μm cell library, the core only occupies less than half of the die, so you can use the rest of the silicon to further integrate the system. In addition, reduced geometry means higher clock speeds.

For any given geometry, a hard core usually does occupy less die area than an equivalent soft core. Hard cores are generally designed from the ground up at the transistor level and therefore achieve better silicon utilization than soft cores. But this hard-core advantage is academic for new μPs, which use the soft-core approach and silicon compilation. It's thus very likely that soft cores will predominate in the future.

Adopt a building-block approach

Just as you can see in the current developments in silicon compilation, other tools used by IC manufacturers to design ICs today will probably end up in the hands of ASIC design engineers tomorrow. Knowing the techniques that companies are using to make 16-bit microcontrollers can give you insights into the tools that will become available to ASIC designers over the next few years. Consider, for example, SGS-Thomson Microelectronics' ST9 HCMOS microcontrollers. These microcontrollers all use the same 16-bit core μP, tailored to the requirements of particular application areas by various combinations of memory and peripheral cells.

To produce a particular variant of the microcontroller, SGS-Thomson can choose from a range of peripheral macrocells, including a multifunction 16-bit timer/counter; a timing processor that relieves the core of real-time control tasks; a full-duplex, synchronous/asynchronous, serial-communications controller; parallel I/O ports; and an 8-channel, 8-bit A/D converter. Memory cells allow the on-chip implementation of as much as 24k bytes of ROM or EPROM, 2k bytes of RAM, and 2k bytes of EEPROM. In addition, you can expand memory off chip to 128k bytes, or, if you add an MMU, to 16M bytes.

To simplify floor-planning and routing, the core μP, memory cells, and peripheral cells all have rectangular footprints with constant lengths and variable widths. Floor-planning simply involves placing these rectangular cells alongside each other in an appropriate order and adding on-chip address and data buses to interconnect the cells. It's like taking a conventional pc-board-level μP system, composed of discrete μP, memory, and peripheral devices, and collapsing it onto a single piece of silicon (**Fig 2**). But because the on-chip peripherals don't have the pin-count limitations of their discrete counterparts, you have much more latitude in the way you connect the cells. For example, you can easily implement multilevel daisy-chain interrupt schemes similar to those you'd expect to find on backplane-bus computer systems.

Although the ST9 building-block concept is simple, the design tools required to provide design flexibility and simulate the design are complex. The company is currently using the technique to produce standard EPROM- or ROM-based enhanced microcontrollers rather than adapting the technique for ASIC design. If you're prepared to commit to 500,000 or more pieces,

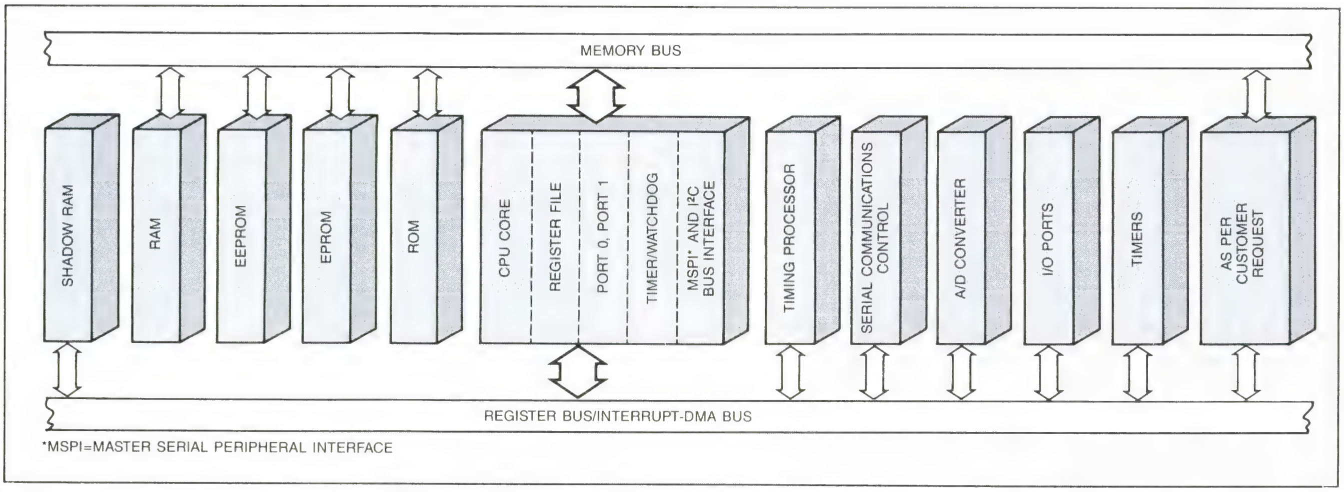


Fig 2—Designing a core-μP system *is like collapsing a pc-board-level system onto a single chip. This diagram from SGS-Thomson represents both the architectural and physical layout of a single core-μP system.*

TABLE 1—REPRESENTATIVE CISC μP AND μC CORES FOR SEMICUSTOM IC DESIGN

VENDOR	CORE TYPE NUMBER	COMPATIBLE STANDARD μP OR μC	NUMBER OF BITS	MAXIMUM CLOCK SPEED (MHz)	PROCESS GEOMETRY (μm)	STANDARD PERIPHERAL MEGACELLS IN ASIC LIBRARY (IN ADDITION TO RAM AND ROM BLOCKS)	WORKSTATIONS SUPPORTED
GE/RCA SOLID STATE	RS20C51	80C51	8	16	1.5, 1.2	65C51 UART, 80C51 SERIAL PORT AND TIMERS, ANALOG FUNCTIONS	DAISY, MENTOR, VALID
INTEL	80C51	80C51	8	16	—	BAUD-RATE GENERATOR, UART, TIMER, SPECIAL FUNCTION REGISTER BUS INTERFACE, ADC	DAISY, MENTOR
LSI LOGIC	L1750A	L64500	16	25	1.5	—	APOLLO, IBM, MIPS, SUN, VAX
NATIONAL SEMICONDUCTOR	SCOP881	COP888	8	10	2	EEPROM, UART, EXPANDER CELL, CLOCK PAD CELL, ADC	DAISY, FUTURENET, MENTOR, SUN
	94C50	F9450, 1750A	16	20	2.0, 1.6	EEPROM, UART, TIMERS, ADC	MENTOR, NATIONAL SEMICONDUCTOR
	HPCCOREA	HPC16003	16	17	2	EEPROM, UART, ADC	DAISY, FUTURENET, MENTOR, VALID
NEC ELECTRONICS	μPD78K/I	μPD78K/I	8	12	1.2	EEPROM, μPD72xxx-SERIES PERIPHERALS, μPD71xxx-SERIES PERIPHERALS, DSP PROCESSOR, ADC, DAC, ANALOG FUNCTIONS	DAISY, MENTOR, PC-VISTAS
	μPD78K/II	μPD78213	8	12	1.2	EEPROM, μPD72xxx-SERIES PERIPHERALS, μPD71xxx-SERIES PERIPHERALS, DSP PROCESSOR, ADC, DAC, ANALOG FUNCTIONS	DAISY, MENTOR, PC-VISTAS
	μPD78K/III	μPD78320	8	12	1.2	EEPROM, μPD72xxx-SERIES PERIPHERALS, μPD71xxx-SERIES PERIPHERALS, DSP PROCESSOR, ADC, DAC, ANALOG FUNCTIONS	DAISY, MENTOR, PC-VISTAS
	μPD78AD	μPD78C10	8	12	1.2	EEPROM, μPD72xxx-SERIES PERIPHERALS, μPD71xxx-SERIES PERIPHERALS, DSP PROCESSOR, ADC, DAC, ANALOG FUNCTIONS	DAISY, MENTOR, PC-VISTAS
NCR MICROELECTRONICS	NCR29116	29116	16	10	1.5, 1.0	EEPROM, DUAL-PORT RAM, MULTIPLIER, MAC, FIFO, COUNTER, 82Cxx-SERIES PERIPHERALS, 2900-SERIES BIT/SLICE CELLS, MANCHESTER ENCODER/DECODER, SCSI INTERFACE, ANALOG FUNCTIONS	DAISY, MENTOR
	65CX02	6502	8	4	2.0, 1.5	EEPROM, DUAL-PORT RAM, FIFO, MULTIPLIER, MAC, TIMER, NON-VOLATILE LATCH, COUNTER, 82Cxx-SERIES PERIPHERALS, SCSI INTERFACE, ANALOG FUNCTIONS	MENTOR
	MPU6805	68HC05C4	8	4	2	EEPROM, DUAL-PORT RAM, UART, SERIAL PERIPHERAL INTERFACE, PARALLEL I/O PORT, TIMER, FIFO, OSCILLATOR, MULTIPLIER, MAC, 82Cxx-SERIES PERIPHERALS, ADC, DAC, ANALOG FUNCTIONS	MENTOR
SEATTLE SILICON	Z80	Z80	8	20	1.5	—	MENTOR
SIERRA SEMICONDUCTOR	COP800	COP820, COP888	8	20	2.0, 1.5	EEPROM, UART, I/O PORTS, REAL-TIME CLOCK, WATCHDOG TIMER, COUNTER/TIMER, LCD CONTROLLER, KEYBOARD ENCODER, I²C-BUS INTERFACE, ANALOG FUNCTIONS	MENTOR, SIERRA
STANDARD MICROSYSTEMS	6502	6502	8	4	2.0	UART, ARCNET CONTROLLER, 5250 TWINAX CONTROLLER, 3270 COMMUNICATION CONTROLLER, FLOPPY DISK CONTROLLER, HARD DISK CONTROLLER, DISK DATA SEPARATOR, ADC, DAC, USART, INTEL 82xx-SERIES PERIPHERALS, REAL-TIME CLOCK, MOUSE DRIVER, KEYBOARD INTERFACE, CENTRONICS PORT	MENTOR, SUN, IBM PC/AT
WESTERN DESIGN CENTER	W65C02	6502	8	10	3.0 TO 1.5	UART, WATCHDOG TIMER, TIMERS, PULSE WIDTH MEASUREMENT TIMER, TONE GENERATOR	CALMA GDS2, VAX, APPLE II
	W65C134	65C134	8	10	3.0 TO 1.5	UART, WATCHDOG TIMER, TIMERS, PULSE WIDTH MEASUREMENT TIMER, TONE GENERATOR	CALMA GDS2, VAX, APPLE II
	W65C816	65C816	16	10	3.0 TO 1.5	UART, WATCHDOG TIMER, TIMERS, PULSE WIDTH MEASUREMENT TIMER, TONE GENERATOR	CALMA GDS2, VAX, APPLE II
	W65C265	65C265	16	10	3.0 TO 1.5	UART, WATCHDOG TIMER, TIMERS, PULSE WIDTH MEASUREMENT TIMER, TONE GENERATOR	CALMA GDS2, VAX, APPLE II
ZILOG	Z8	Z8	8	10	2.0, 1.6	—	—
	Z80	Z80	8	10	2.0, 1.6	—	—
	Z8000	Z8000	16	16	2.0, 1.6	—	—

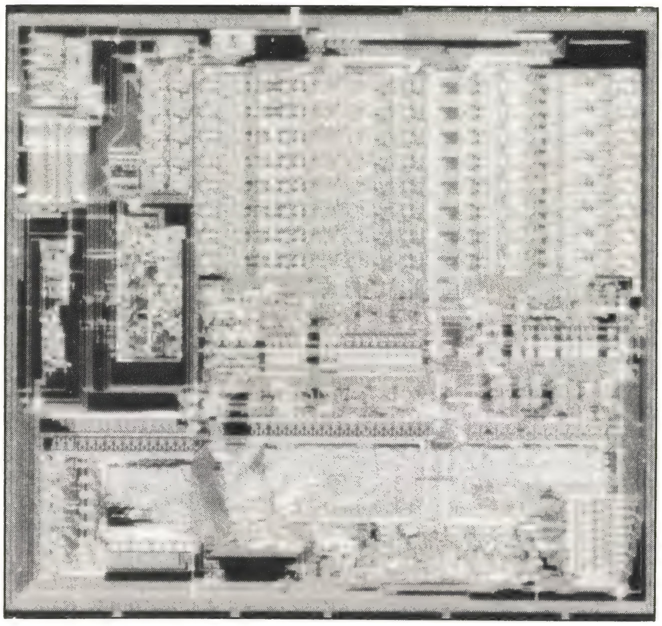
The building-block approach used by microcontroller manufacturers lets you integrate an entire μP system onto a single chip.

SGS-Thomson will design a custom ST9 microcontroller for you, but it concedes that it may make those in-house design tools publicly available, so that users who need fewer parts can design their own. Motorola and Zilog also show a preference for producing a standard set of enhanced microcontrollers. Motorola bases its designs on its 6805 and 68000 core μPs, and Zilog bases its on its Z8, Z80, and Z8000 cores.

NEC Electronics Inc has also been using functional macrocells in house for some time to design its microcontroller products, and it's already in the process of putting these macrocells and the appropriate design tools into the hands of semicustom-IC designers. In addition to the 7400 Series logic cells, NEC's ASIC library includes various macrocells derived from the company's standard 8-bit μPD family of products. Currently available μP cells include cores of the 78K/I and 78C10 8-bit μPs, with cores of the 8-bit 78213 and 78320 slated for introduction during first half of this year.

Peripheral cells now available from the μPD family include functional equivalents of the company's 71051 serial-I/O controller, 71054 programmable timer, 71055 parallel-interface unit, 71059 interrupt controller, 71071 DMA controller, 71088 system bus controller, and 72065 floppy-disk controller. NEC plans to introduce the 72020 graphics processor, 77C25 DSP chip, 72061 hard-disk controller, and the 72067 and 72068 floppy-disk controllers this year.

NEC also expects to add 8k-byte and 64k-byte mask-programmed ROM macrocells and a 256-byte EEPROM macrocell to the already available 16k-byte PROM and 2k-byte static-RAM macros sometime this year. Current workstation support allows you to design macrocells for user-defined logic, combine these with the appropriate core-μP and peripheral-device macrocells, and perform system-level design-rule checks. Functional and timing simulation, fault grading, and placement and routing is then carried out on NEC's mainframe. The company plans to introduce a series of analog macrocells as well.



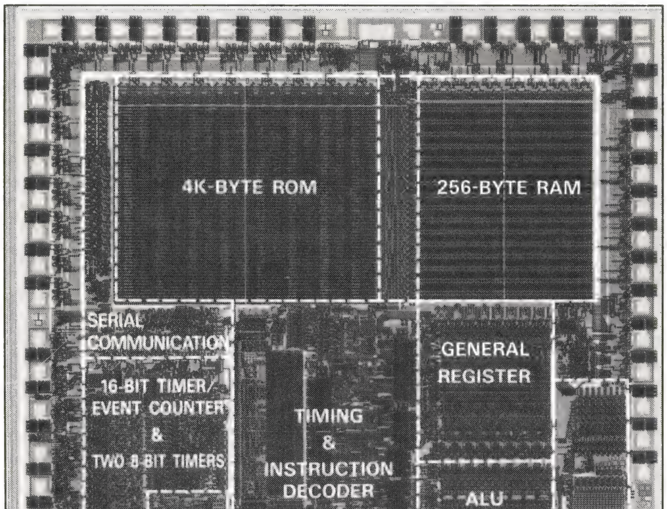
This 68C05 core μP from the ASIC library of NCR Corp illustrates the high silicon utilization attainable with a hard core. It executes the instruction set of Motorola's MC68HC05C4 microcomputer.

TABLE 2—REPRESENTATIVE RISC μP CORES FOR SEMICUSTOM IC DESIGN

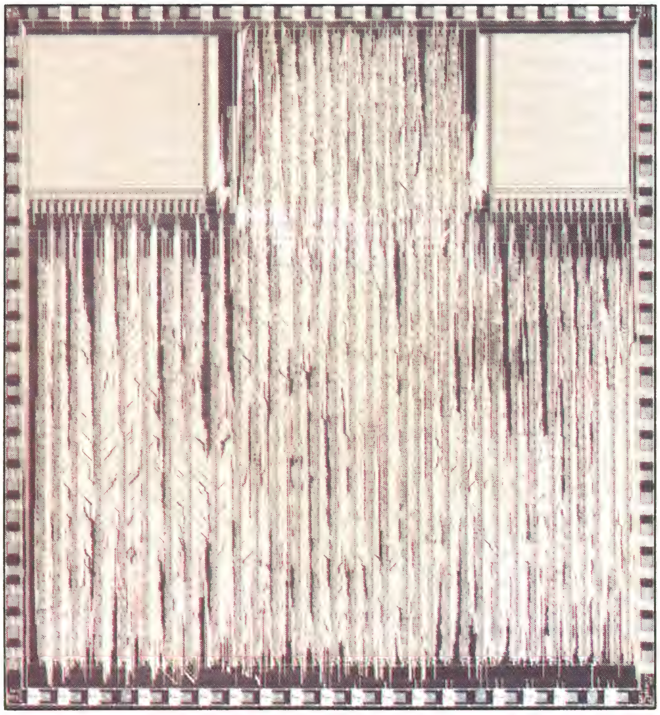
VENDOR	CORE TYPE NUMBER	COMPATIBLE STANDARD μP	NUMBER OF BITS	MAXIMUM CLOCK SPEED (MHz)	PROCESS GEOMETRY (μm)	STANDARD PERIPHERAL CELLS IN ASIC LIBRARY (IN ADDITION TO RAM AND ROM BLOCKS)	WORKSTATIONS SUPPORTED
HARRIS	RTX2000	RTX2000	16	—	—	INTERRUPT CONTROLLER, STACK CONTROLLER, MULTIPLIER, TIMER, CLOCK GENERATOR, PARALLEL I/O CONTROLLER, UART, 1553B CONTROLLER	—
LSI LOGIC	L64801	SPARC L64801	32	25	1.5 1.0	—	APOLLO, MIPS, MICROVAX, SUN
	LR3000	MIPS LR3000	32	20	1.5 1.0	LR3010 FLOATING POINT ACCELERATOR, LR3020 WRITE BUFFER	APOLLO, IBM, MIPS, SUN, VAX
VLSI TECHNOLOGY	VL86C010	ACORN ARM	32	20	1.5 1.0	—	APOLLO, HP, SUN, VAX, AND OTHERS

Although 8-bit microcontrollers have been the center of activity for core μPs, core processors are beginning to shake off their 4- and 8-bit images. National Semiconductor currently offers the company's 16-bit HPC16003 μP as an ASIC core; LSI Logic can provide an implementation of a 16-bit MIL-STD-1750A processor; and you can expect to see the 16-bit 80C186 μP appear in Intel's ASIC library sometime this year. Other recent introductions include NCR's 29116 16-bit core, Western Design Center's W65816 16-bit core, Zilog's Z8000 16-bit core, and Motorola's 68000 32-bit core. In fact, because contemporary processor designs are usually based on standard-cell techniques, you can expect most μP manufacturers that have their own ASIC divisions to follow suit with their latest μP offerings.

Because of their standard-cell design, most 16- or 32-bit RISC processors are also available as core μPs. LSI Logic has implemented a core of Sun Microsystems' SPARC architecture and another core based on MIPS Computer Systems' 32-bit RISC processor. VLSI Technology offers a core based on the VL86C010 RISC processor (Acorn Computers (Cambridge, UK) originally designed this processor using VLSI's semicustom design tools). Furthermore, Harris Corp's standard-cell library includes an RTX2000 RISC-



***You can combine** the μPD78AD core μP from NEC Electronics Inc with ASIC library megacells that are functionally compatible with the company's 72xxx and 71xxx Series peripherals.*



***Suited to real-time embedded controller applications,** the 16-bit RTX2000 core μP available in Harris Corp's standard cell library directly executes the Forth programming language, eliminating the need for assembly language programming.*

processor core that should be of particular interest to embedded-controller designers and Forth devotees—it executes Forth directly, eliminating the need for program compilation.

RISC and ASIC go hand-in-hand

In fact, RISC processors are well suited for use as core μPs because they occupy less silicon area than high-performance CISC cores. RISC cores are smaller because they have a simpler internal architecture than CISC processors and require little or none of the microcode ROM and state machines that CISC cores need to support their extensive instruction sets. Because RISC processors execute a single instruction in a single clock cycle, the instruction itself has to replace the microcode. RISC processors thus need wide instruction and data buses; they must also be coupled to very fast memory systems that can feed the processor with instructions and data at clock speeds between 20 to 30 MHz.

High-speed memory access and wide instruction and data buses favor the use of on-chip cache memories. ASIC libraries that include RISC cores and compilable memory blocks allow you to generate on-chip cache-memory architectures that are optimized to exploit the RISC processor's speed potential. In addition, because the RISC core won't eat up all of the silicon, you stand a better chance of implementing realistically sized caches.

LSI Logic claims that its latest LCB007 0.7-μm channel-length process lets you design cell-based ASICs that include a RISC core, plus 32k bits of RAM, 512k bits of ROM, and around 30k gates worth of

Cores of 32-bit RISC processors don't occupy as much silicon as their CISC counterparts.

random logic. The company plans to enhance its Modular Design Environment (MDE) ASIC-design tools to support those designs, and will make the MDE tools available during the second half of this year.

Core μPs complicate simulation

When you add a core μP to an ASIC, you must accept that it greatly increases the complexity of simulating the design. Rick Rasmussen, director of Microprocessor Marketing for LSI Logic Corp, believes that μP simulators should be able to work at four different levels: instruction-set-architecture level (ISA); the behavioral-model level (BML), which involves all I/O operations); register-transfer level (RTL); and the gate level. LSI Logic can currently simulate its core μP's at all of these levels except the register-transfer one.

Simulation at the ISA level is important because it allows you to run target-system software on the simulator. This type of simulation is particularly significant if you're integrating a RISC processor into the design: You can only obtain maximum performance out of a RISC-based computer if you design the operating system, programming language, language compiler, and the RISC processor's architecture and instruction set as an integrated set of functions. Only by running the operating system and potential application programs on the simulator can you benchmark different solutions against one another, thereby ensuring that you get the

Manufacturers of core μPs

For more information on core μPs such as those described in this article, contact the following manufacturers directly, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service.

Eurosil Electronic GmbH
Erfurterstrasse 16
8057 Eching
West Germany
(089) 319060
FAX 089-3194621
Circle No 650

Fujitsu Microelectronics Inc
3330 Scott Blvd
Santa Clara, CA 95054
(408) 727-1700
FAX 408-922-9128
Circle No 651

GE Solid State
724 Route 202
Somerville, NJ 08876
(201) 685-6000
FAX 201-685-6487
Circle No 652

Harris Semiconductor Box 883
Melbourne, FL 32902
(407) 724-7418
FAX 407-729-5691
Circle No 653

Hitachi America Ltd
Semiconductor and IC Division
2210 O'Toole Ave
San Jose, CA 95131
(408) 435-8300
Circle No 654

Hitachi Ltd
New Marunouchi Bldg 5-1
Marunouchi 1-Chome
Chiyoda-ku, Tokyo 100
Japan
(03) 212-1111
Circle No 655

Intel Corp
6501 W Chandler Blvd
Chandler, AZ 85226
(602) 961-8051
FAX (602) 961-4335
Circle No 656

LSI Logic Corp
1551 McCarthy Blvd
Milpitas, CA 95035
(408) 433-8000
FAX 408-434-6422
Circle No 657

Motorola Inc
3501 Ed Bluestein Blvd
Austin, TX 78721
(512) 928-6000
FAX 512-928-6718
Circle No 658

National Semiconductor Corp
2900 Semiconductor Dr
Santa Clara, CA 95051
(408) 721-5000
FAX 408-730-5659
Circle No 659

NCR Corp
Microelectronics Division
2001 Danfield Ct
Fort Collins, CO 80525
(303) 226-9500
FAX 303-226-9556
Circle No 660

NEC Electronics Inc
Natick Technology Center
One Natick Executive Park
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(508) 655-8833
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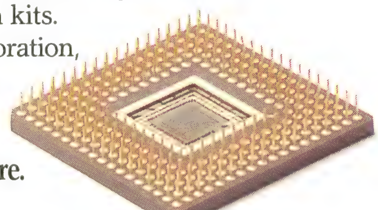

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overall system design right before committing yourself to the expense of silicon.

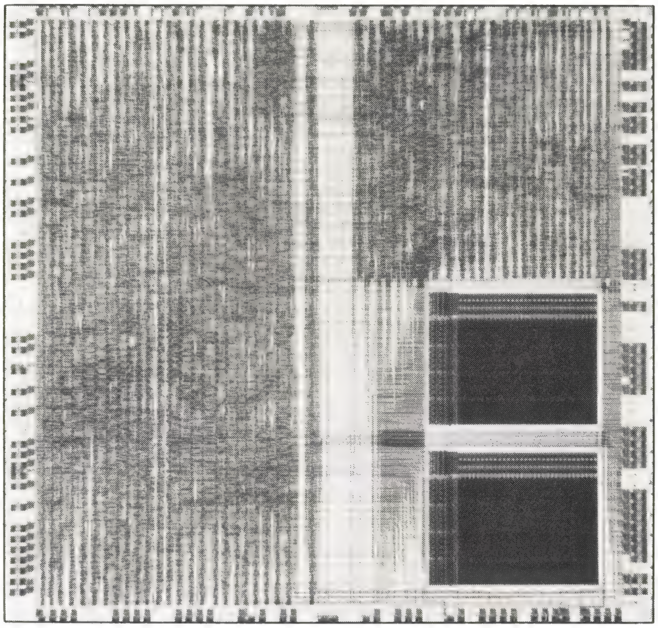
Simulate rather than emulate

Emulating an ASIC design in hardware—especially if it contains a core μP—can be difficult. So being able to run target-system software on a simulator is a very valuable debugging aid. LSI Logic's Rasmussen believes that for data-processing types of systems (systems designed to run Unix, for instance), simulation can eliminate the need for hardware emulation completely.

Gate-level simulation gives you the detailed, subnanosecond timing data necessary to determine the maximum speed of your design, and to evaluate, for example, whether memory and peripheral access can keep pace with the processor's demand for instructions and data. Rasmussen cites the ability to perform both behavioral- and gate-level simulations as a key argument in favor of soft core μPs. Because ASIC vendors can break a soft core down into gate-level building blocks, they can easily generate, at a minimum, both behavioral- and gate-level models. Although a hard core has a behavioral-level model, no accurate gate-level model is available. In addition, if you modify a soft core to change its functions, its gate-level model automatically adjusts to the modified design.

Simulation alone won't necessarily solve all your debugging problems. It might allow you to fully debug a design with a memory-intensive architecture, such as one targeted for data processing, or possibly one that's running a high-level language real-time operating system. But it's unlikely to allow you to dig all the bugs out of an I/O-intensive design for an embedded-controller application.

Embedded controllers usually have to cope with a large number of asynchronous external inputs, and it's usually the interaction between these inputs and the program flow that causes problems. To make matters worse, you may have to program the embedded controller in assembly language to achieve the required real-time program response or to pack the program into the available ROM space. Admittedly, this is less likely to happen than it was 10 years ago because high-level-language compilers are so much better than they used to be. In any event, to debug such a system, you'll need all the facilities you'd expect to find on a hardware emulator for a standard μP, including the ability to display and change register and memory contents, multilevel program-trace triggering, setting breakpoints on single instructions, and single-stepping. And you'll also need an emulator that takes account of all the custom logic that surrounds the core μP too.



The L64801 32-bit RISC processor core *from LSI Logic provides an implementation of Sun Microsystem's SPARC architecture. This year it will be introduced into the company's 0.7-μm channel-length LCB007 standard cell library.*

Emulation leaves much to be desired

You currently have no dependable alternative to designing your own emulation hardware by breadboarding the ASIC. To assist in breadboarding, some ASIC vendors will sell you parts that contain their most complex library elements. NEC, for one, provides compatible silicon for each of the company's core μP and peripheral device macrocells in PGA packages that you can plug into the company's universal emulation board. The emulation board interfaces both with a breadboard of user-defined logic and memory devices, and with an IBM PC. The PC supports a symbolic debugger and a relocatable assembler.

NCR Corp supports its 6805 core microprocessor with a similar arrangement consisting of 3 interconnecting pc boards: a CPU module, a debug module, and a user module. The CPU module contains a special version of the 6805 core plus control logic and bus buffers. You breadboard the rest of your ASIC design on the user module, which connects on one side to the CPU module and on the other to your target system. To debug, you place the debug module between the

Compared to standard µP emulators, core-µP emulation leaves a lot to be desired.

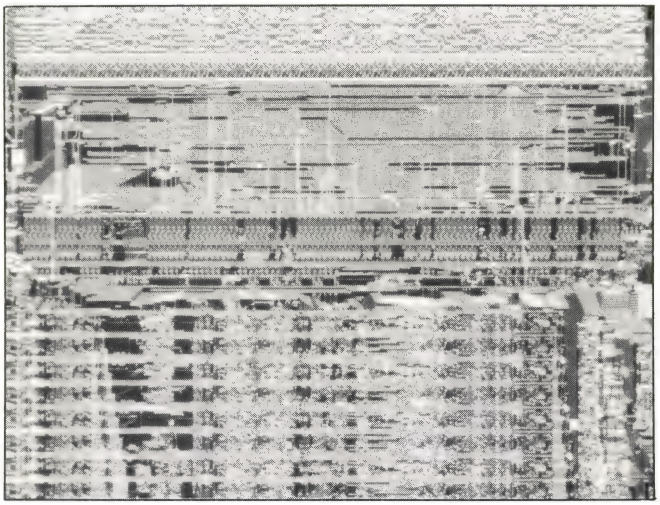
CPU and user module. The debug module has an RS-232C serial link to a terminal or host computer and an EPROM-resident debug monitor that provides you with a set of fairly simple emulation commands, like downloading object code, running a program from a specified address, setting and clearing breakpoints, displaying and modifying register or memory, and executing simple program-trace instructions. To provide more sophisticated triggering and program-tracing facilities, you'd have to hook the system up to a good logic analyzer.

The fundamental drawback in emulating an ASIC in this manner, however, is that you can't hope to emulate it at full speed. NCR's evaluation system, for example, operates at bus speeds that are as fast as 2 MHz, but an ASIC containing the company's 6805 core µP can handle bus speeds that are twice as fast. And submicron ASICs can operate at 20 MHz.

Testability remains one of the key issues to be solved in the effective integration of core µPs into ASICs. The existence of the core µP on the chip works both for and against you when you're trying to test the ASIC. It works against you because the core µP is a highly complex piece of logic that is connected to, and often made inaccessible by, other complex logic blocks and user-defined random logic—all of which makes it difficult to test. On the other hand, having a core µP in the ASIC also works for you, because once you've found a way of verifying that the core is functional, you can use it to ease the testing of the surrounding peripheral devices and user-defined logic.

To effectively test the core µP, you must be able to control and observe all of its I/O pins. NEC, for example, will supply test vectors for all of its core µPs and peripheral device macrocells, but to use those test vectors, you must incorporate on-chip testability logic that allows you to isolate each macrocell from all other on-chip macrocells. What's more, you must provide access to all of the macrocells' I/O lines via external package pins. Since any macrocell's I/O lines may well outnumber the pins on the ASIC package, you may have to include multiplexers or scan-path logic to reduce the number of I/O pins required for testing.

If you're considering using a core µP for the first time, remember that the technology is still in its infancy. There's still a great deal of debate about how to solve problems involved in simulation, emulation, and testability, and you may well find yourself traveling roads that haven't been taken too many times before. Also, development costs can be high—only the



While retaining software compatibility with the NMOS 6502 µP, *this 65CX02 core µP from NCR Corp adds an additional 59 op codes, 14 new instructions, and two new addressing modes to the 6502 instruction set.*

latest generation of high-performance workstations are capable of running target-system software at the simulator level.

For embedded controller applications, unless you've got a good reason to put as much of your systems functions as possible onto a single chip, or unless you're prepared to commit to very high volumes, you may be better off using one of the many enhanced microcontrollers currently on the market; you can then place additional peripherals or user-defined logic in a conventional ASIC. But, if you looking for the ultimate in 32-bit system performance, you'll find that the ability to modify a soft-core µP's functions, and to combine the core with other on-chip high-level functions, lets you develop computers that fully exploit the potential of today's very high-speed silicon technologies. EDN

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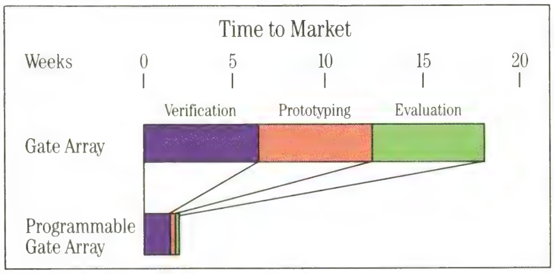

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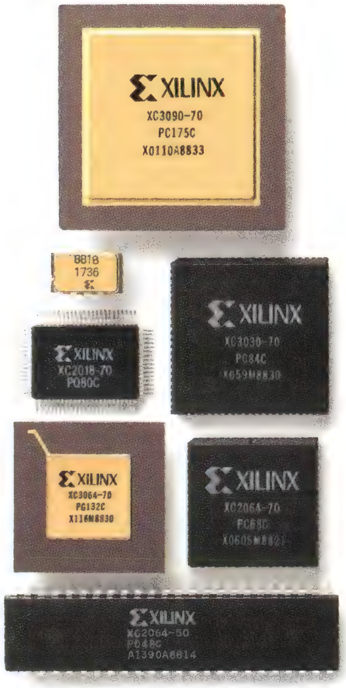

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CIRCLE NO 73

Designed-in safety features ease compliance

For several reasons, you should make compliance with accepted safety standards a primary goal during the initial design phase. Once you're familiar with the standardized regulations and tests, you can design your electronic data-processing and telecomm equipment confident that it will comply with OSHA's standards.

Glen Dash, *Dash, Straus & Goodhue Inc*

Incorporating safety-related features into your electronic-equipment design should be far more than a peripheral or "by the way" consideration. Whether you're designing a circuit, a pc board, or an enclosure, considering safety early in the product design cycle will save you time, money, and inconvenience.

Any electronic system destined for use in the workplace must comply with standards dictated by organizations such as OSHA (in the US), CSA (in Canada), and IEC (in Europe) (see the **boxes,** "There's no such thing as voluntary compliance," and "Safety approvals differ from country to country"). Depending on the target market for your product, you'll have to take into account one, two, or all three of these organizations' standards. And finally, proof of testing may shield you against civil and criminal liability if injury does occur.

Considering that compliance is a requirement, it makes sense for you to consider safety aspects early on. Choosing the best components from the beginning—that is, those that already comply with their own individual standards—may save you from performing specialized tests. Including in your design items such as impedance-protection circuitry, thermal cutoff devices, and interlocking mechanisms can prevent possible redesign and retrofit later on. Ultimately, designed-in safety features that ensure compliance or make testing much easier will lighten an expensive load in your production department.

What are the four harms?

The purpose of all safety standards is to prevent the possibility of property loss or injury. More specifically, you want to avoid the so-called "four harms": electrical shock, fire, mechanical hazards, and exposure to high energy levels. Except for the mechanical hazards, the harms stem from exposure to electrical levels (volts, amperes, Joules) that can give rise to hazardous conditions.

The US OSHA standards explicitly define these four harms:

- Electrical shock—potential for risk arises when an operator is exposed to circuitry whose voltage exceeds 30V rms, 42.4V peak, and whose current

Equipment designed with safety in mind should protect personnel from the four harms: electrical shock, fire, mechanical injury, and high energy levels.

can exceed 5 mA through a 1.5-kΩ resistor.

- Fire—danger occurs when temperature increases exceed prescribed limits, and in circuits whose voltage and current capabilities exceed 42.4V, 8A peak.
- Mechanical hazards—physical danger is caused by moving parts, sharp corners and edges, and products that can tip over.
- High-energy levels—situation becomes risky when a potential of 2V or more between adjacent parts can produce a continuous volt-ampere level exceeding 240 VA, or in which reactive components can produce energy levels exceeding 20J. Such energy levels can produce metal meltdown, resulting in the splattering of flaming material.

Two of the most widely followed US standards that address protection against these hazardous conditions are UL 478, which covers electronic data-processing (EDP) equipment, and UL 1459, which covers telecommunications equipment. When the two equipment categories overlap (for example, in the case of modems), the somewhat-more-stringent UL 478 takes precedence. In Canada, the EDP and the telecommunications standards are CSA C22.2 Nos 220 and 0.7, respectively. In general, the Canadian specs accept all tenets of the UL standards, even though separate approvals are required. For most of Europe, IEC 950 covers EDP equipment (see **box,** "IEC 950: UL 478's European counterpart").

In addition to these end-equipment safety standards, a number of individual standards apply to the components used in EDP and telecomm equipment (**Table 1**). Components that fall under these separate regulations should meet both the individual standards and the end-equipment standard. For example, a power supply for an EDP application must satisfy both UL 1012 and UL 478.

TABLE 1—INDIVIDUAL COMPONENT STANDARDS

COMPONENT	UL STANDARD NO
POWER-SUPPLY LINE CORDS	817
TRANSFORMERS	1585, 1310
POWER SUPPLIES	1012
EMI FILTERS	1283
FUSES	198
FUSE HOLDERS	512
SWITCHES	20, 1054
WIRE AND CABLE	486A, 486B, 83
PRINTED-CIRCUIT BOARDS	796
PLASTIC PARTS	746C
PLUGS AND RECEPTACLES	498
CATHODE-RAY TUBES	723
CIRCUIT BREAKERS	489
MOTORS	519

The more familiar you are with the specific aspects of designing equipment with safety approvals in mind, the better your chances of designing acceptable equipment. First of all, be sure to read the spec very carefully; there are many specific definitions.

There's no such thing as voluntary compliance

To many manufacturers, it's unclear whether they are legally compelled to submit their equipment to a listing agency. Some manufacturers are under the impression that it is voluntary. In fact, it's mandatory. Any device intended for the workplace has to comply with OSHA regulation, section 1910.399: "Electronic equipment . . . is acceptable . . . if it is . . . listed . . . by a nationally recognized testing laboratory . . . ."

The use of unlisted equipment can result in a host of federal penalties, including fines and imprisonment. And, even though criminal liabilities for unlisted products can be significant, civil liabilities are equally scary. Worse, even if the injured party chooses not to sue, his or her insurance company might. For example, if an injured person applies for workmen's compensation, the insurer for the compensation plan might try to recoup its losses from an equipment manufacturer under the legal principle of "subrogation."

Standards such as UL 478 represent a benchmark for the due care required of all manufacturers under product-liability law. Failure to meet the appropriate standard can itself be construed as proof of negligence if compliance could have prevented the injury. A listing thus serves as a shield (albeit an incomplete one) for the manufacturer, and failure to achieve listing provides a sword for the plaintiff.

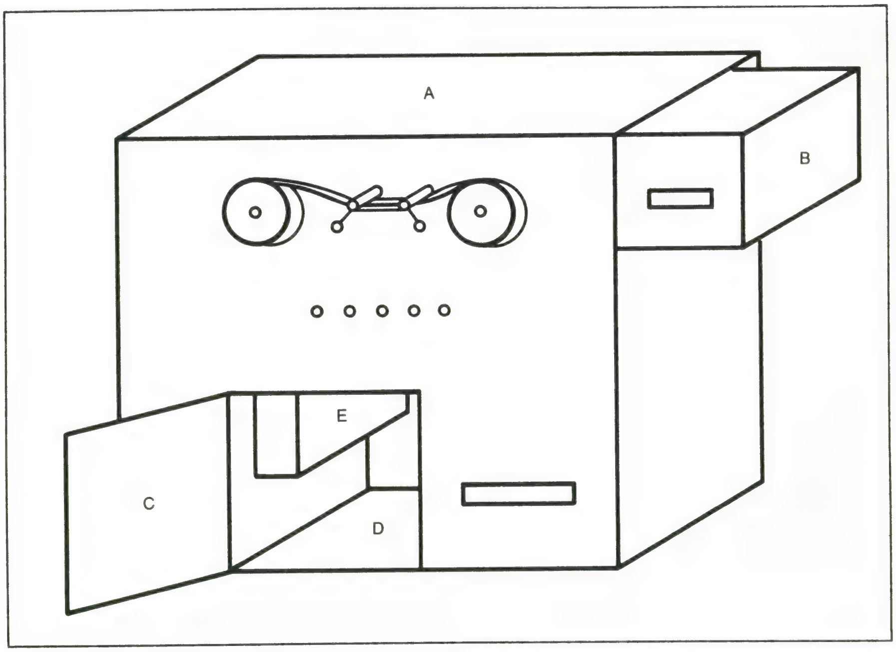

***Fig 1—A typical piece of equipment for EDP applications** has several protection mechanisms. The enclosure (A) provides basic protection against fire and shock dangers. The housing (B) protects personnel from fire, shock, and mechanical injury. The internal barrier (E) prevents access to hazardous areas inside the equipment. The bottom panel (D) keeps flaming material inside the equipment.*

For instance, don't confuse "Roman numeral" Class I and Class II circuitry with "Arabic numeral" Class 1 and Class 2 devices. Class I circuits and devices are those housed in metal enclosures; Class II are housed in plastic. These definitions are completely unrelated to the definitions for Class 1 and 2 devices, which refer to a circuit's voltage and current rating. Class 2 circuits receive their power from supplies whose maximum peak open-circuit voltage is 42.4V and whose short-circuit current capability is lower than 8A.

You should also be aware of different definitions for different types of insulation. Double insulation refers to a part's basic insulation plus an additional layer (supplemental insulation) that protects against shock. Reinforced insulation serves the same purpose as double insulation, but is a single layer.

Safety and testing specifications for UL 478, as is the case with most UL standards, fall into two categories: construction specs and performance specs. As you learn more about designing-for-safety, you'll find that the terms used to describe a piece of equipment's packaging and protective covering have specific meanings. The typical assembly in **Fig 1,** for example, is labeled according to the UL nomenclature. The enclosure (A) provides basic protection against fire- and shock-related injuries. During the approval process, the external housing (B) undergoes investigation either as an enclosure if it protects against fire or shock, or as a guard if it protects against mechanical injury. The operator-access door is labeled C; hazardous areas inside the enclosure thus need barriers (E). A bottom panel (D) must meet its own strict criteria. Enclosures, guards, and barriers must use materials that are not combustible. These include steel, corrosion-protected aluminum, or heat-resistant glass that's tempered, wired, or laminated.

Any plastic materials that you use must meet UL-standard flame ratings:

- 94HB material can burn but only at some specified maximum rate. It is acceptable for use in cabinets and guards.
- 94V-5 material can flame or glow, but it can't release flaming or glowing particles. It is acceptable for enclosures and barriers for floor-mounted equipment.
- 94V-0 and 94V-1 material can release particles, as long as these don't ignite surgical cotton. These materials are acceptable for table- or rack-mounted equipment.
- 94V-2 material can release flaming particles that ignite surgical cotton.
- 94HF-1 plastic-foam material does not ignite surgical cotton.
- 94HF-2 plastic-foam material can ignite surgical cotton.
- 94HBF plastic-foam material burns at a specified maximum rate.

If you plan to use conductive coating for EMI sup-

In addition to meeting end-equipment safety standards, you should make sure the components in your apparatus satisfy their individual standards.

pression, you have to get UL approval for the paint and plastic, as well as the facility that applies the coating. In addition, all the parts used in EDP equipment (except for Class 2 circuits), including pc boards, wiring, and connectors, must have ratings of 94V-2, 94HF-2, or better. Externally mounted air filters must satisfy the more relaxed 94HB or 94HBF ratings.

Keep hazardous parts out of reach

Equipment that has to have openings—for ventilation for example—also has strict regulations. In general, you have to test the openings by using a finger-like IEC articulated probe **(Fig 2)**. You should not be able to insert the probe into an opening in such a way that it touches any hazardous parts—those that move, are sharp, are hot, or may be exposed to voltages higher than 42.4V.

Moreover, you have to ensure that items such as coins and paper clips, which present a risk of short-circuit-induced fire, can't fall inside the equipment. The openings in the top and on the sides of the enclosure must measure less than 3/16 in. Louvers can be longer than 3/16 in., but you must design them so that they deflect falling parts **(Fig 3)**.

Bottom panels have strict regulations because they must provide protection against falling, flaming parts. In general, bottom panels should be closed, but openings are permitted under wires, receptacles, or impedance-protected or thermally protected motors. In addition, 1/4-in. openings are acceptable under materials that have a flame rating of 94V-1 or better, or in cases where the openings are covered by a second barrier consisting of a stainless-steel mesh screen made of 0.018-in. min diameter wire.

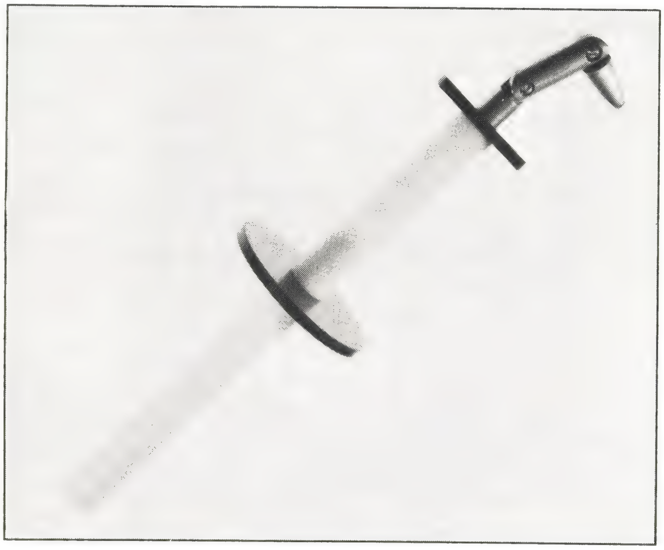

***Fig 2—An articulated probe emulates** the human finger. You use the probe to test the protective qualities of the openings in an enclosure. The IEC articulated test probe shown (you can also build your own from IEC-published schematics) is available from Compliance Design (Boxborough, MA).*

In some EDP applications, an operator might have to reach inside the enclosure—to make adjustments or to replace lamps, for example. To make sure the equipment is powered down in these instances, you have the option of using an interlocking mechanism. If you use an interlock, you'll be able to waive some UL 478 accessibility requirements, provided that the mechanism meets certain other safety standards, For instance, it must not be possible for someone to open the interlock with an IEC articulated probe, and the interlock must require an intentional adjustment before it can be bypassed. The interlock should also be

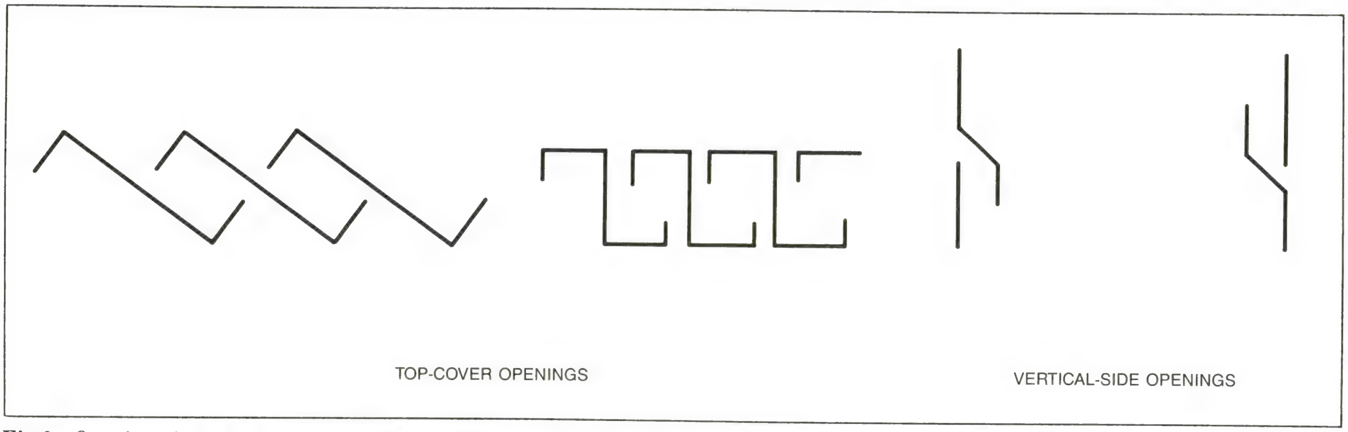

***Fig 3—Openings in an enclosure** must deflect falling parts. These drawings show cross sections of acceptable types of openings that keep out small metal parts that could otherwise cause short circuits and fires.*

mechanical and must open all current-carrying conductors. A solid-state relay may be unacceptable because a single short circuit in the device can render the interlocking mechanism ineffectual. Finally, the interlock must be capable of 100,000 operations.

You'll find that the construction spec governing most of the hazardous conditions associated with EDP equipment is the one that governs the unit's connection to the ac-supply mains. The ac line cord must be permanently attached to the equipment unless it is of an acceptable, detachable form. The line cord must not be longer than 15 ft, and its plug must have a rating of at least 125% of the rated current. A permanently attached line cord must include a bushing and strain-relief feature. For low-power equipment, you can use ac adapters as long as they have component recognition under UL 1310.

TABLE 2—REQUIRED CIRCUIT SPACINGS

VOLTAGE PRESENT V RMS	VOLTAGE PRESENT V PEAK	SPACING IN.	SPACING MM
0 TO 50	0 TO 70.7	3/64	1.2
51 TO 125	72.1 TO 176.8	1/16	1.6
126 TO 250	178.2 TO 353.5	3/32	2.4

The nature of the internal wiring also requires attention, and must be "so routed and secured that neither it nor related electrical connections are likely to be subject to stress or mechanical damage." Specifically, you must ensure that the wiring is properly rated for voltage breakdown and temperature. For wiring that

Safety approvals differ from country to country

Depending on the country—or continent—a piece of equipment destined for the workplace may carry a different safety approval sticker. In the US, OSHA (Occupational Safety and Health Administration) regulations require that all equipment used in the workplace be approved by a "nationally recognized test laboratory." Until recently, the only agencies of this type were Underwriters Laboratories (Northbrook, IL) and Factory Mutual Research Corp (Norwood, MA).

In 1988, however, OSHA began accrediting other laboratories, thereby opening up the field of product listing to competition. The list of approved (or in the process of being approved) laboratories per OSHA 29 CFR 1907 now also includes Dash, Straus & Goodhue (Boxborough, MA) and MET (Baltimore, MD).

In Canada, the Canadian Standards Association (CSA) has an effective monopoly over safety regulations. Here, the regulations are not federal as in the US, but provincial. Nearly every province in Canada requires EDP equipment to be CSA certified prior to sale or installation. CSA, does, however, work closely with a number of nationally recognized test laboratories to facilitate approvals in both the US and Canada.

For members of the European Economic Community (EEC), the Low Voltage Directive 73/23/EEC lists which laboratories can apply a pan-European mark. Member countries such as the UK, France, and Germany cannot require that a computer be tested by a national test house; instead, these countries must accept the approval of any laboratory in the EEC, listed in the EEC's official journal.

Among the most popular laboratories for US-based manufacturers are the BSI in the UK and the France-based AFNOR. West Germany boasts no fewer than 10 EEC-accredited laboratories, the most popular of which are the VDE and the TUV.

The fact that any one of these labs' stickers permits equipment to circulate freely throughout the 12-member EEC signals a major breakthrough for computer manufacturers. Countries outside the EEC, such as Norway, Sweden, and Switzerland, have seen the advantages of the system and have also begun to harmonize their specs with those of the EEC.

Allowing US labs to apply for inclusion in the Low Voltage's Directive list, however, is not likely. US standards still differ substantially from those in Europe, and the EEC is not likely to accredit a US-based laboratory in the near future. Given these circumstances, it's unlikely that OSHA will accredit any European labs either.

In designing equipment to meet national safety standards, the mechanical design is as important as the electrical considerations.

passes through metal guides, you must provide either smooth surfaces or bushings. Any wire that's subject to motion must have some form of auxiliary mechanical protection, such as helical wraps.

The wire must be insulated with PVC, PFE, BTFE, FEP, or neoprene, and it must be marked with a rating of VW1. Splices are permitted, but you must mechanically secure them prior to soldering. In addition, wires that connect to screw terminals must do so by means of a solder lug. You can use the frame of the equipment to carry secondary current, but hinges or conductive coatings are prohibited for this purpose. If planned

IEC 950: UL 478's European counterpart

In contrast with the old days, when you had to apply for approval in each European country where you wanted to sell equipment, you can now follow the "harmonized" IEC specs, which all members of the European Economic Community accept. Because it is similar in principle and intent to UL 478, the spec of most interest here is IEC 950.

The two standards do have several differences, however. One is the acceptability of reinforced insulation in Class II devices. IEC 950 dictates that reinforced insulation is acceptable only in cases where the use of basic and supplemental insulation is clearly impractical.

IEC 950 is strict on the amount of acceptable minimum clearance (shortest distance in air between two parts) and creepage (distance over insulating surface between two parts). Primary circuits must have 3-mm min clearance and creepage between parts of opposite polarity for basic insulation and 4 mm for supplemental insulation. Parts separated by solid insulation have to be at least 1 mm thick to qualify as supplementary insulation and 2 mm thick for reinforced insulation.

The standard also mandates stringent insulation and dielectric tests. First, you have to condition the equipment at 93% relative humidity for two days. You then apply 500V dc for one minute between the secondaries and the enclosure, and then between the primaries and the enclosure. Class II devices have to be wrapped in metal foil. Resistance must exceed 7 MΩ. For the dielectric test, you apply 1250 to 3750V dc between the same points.

Another insulation test is the one governing leakage current. This current can result from the lack of grounding of Class II equipment or from the disconnection of the ground return in Class I units. The limit for most Class I devices is 3.5 mA; for Class II equipment, it is 0.25 mA. Portable Class I machines have a 0.75-mA leakage-current limit.

IEC 950 recognizes Class 2 (note the Arabic numeral) circuits, which IEC standards de-

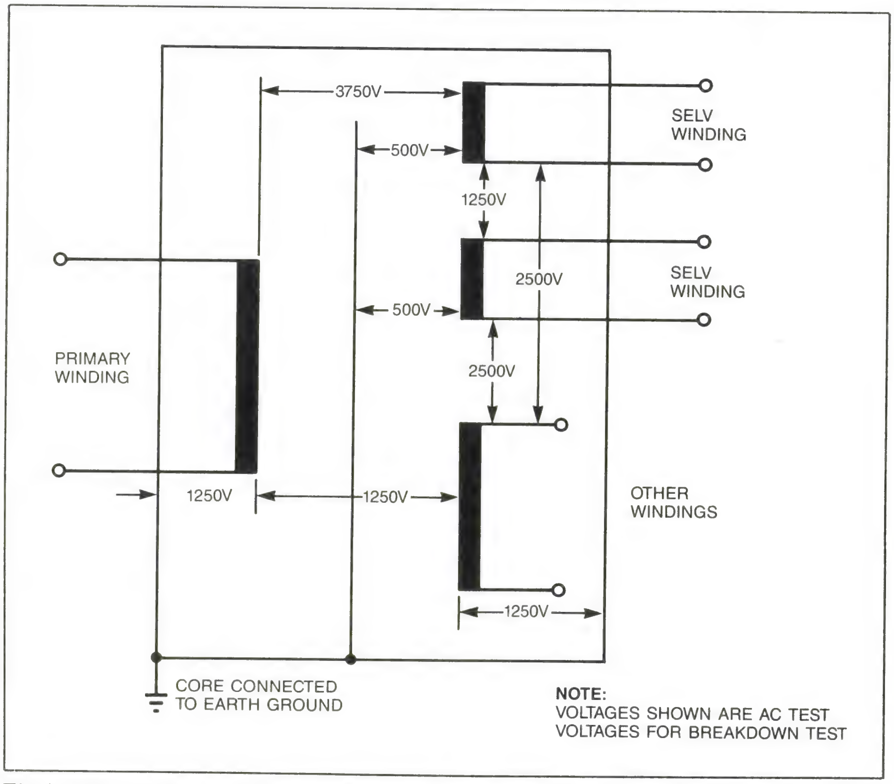

Fig A—IEC requirements for safety isolating transformers *are stringent. The specs require >3750V ac breakdown between the primary and the SELV secondaries and >1250V ac breakdown between all windings and the transformer's case.*

operator servicing entails possible operator contact with the wires, you must provide a second layer of insulation, such as tubing, or else provide an interlocking mechanism.

Spacings between components and uninsulated conductors (pc-board traces, for example) must meet their own particular requirements **(Table 2)**. These specs apply to primary circuitry; to secondary circuitry that operates at more than 100V, 200 VA; and to secondary circuitry such as interlock circuits that is intended as safety protection. The spacing requirements don't apply to circuitry whose series impedance is greater than

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note as "SELV," or safety extra-low-voltage circuits. IEC specs for insulation and isolation are more stringent than UL specs. A SELV circuit's wires and harnesses must be double insulated (for example, with supplemental tubing). Further, the IEC specs for transformers used in SELV circuits are far stricter than the UL standards. **Fig A** shows the IEC breakdown requirements for transformers.

As is the case with UL compliance, all components in a unit have to meet IEC component specs. The use of some components requires special care. For instance, all capacitors greater than 1 μF must be marked with their voltage rating and capacitance. You should not connect capacitors across thermal-cutout devices. Across-the-line capacitors in primaries must have a value lower than 0.5 μF, or they must have a bleeder resistor in parallel that discharges the capacitor to 34V max one second after disconnection.

IEC 950 mechanical-stress tests are similar to those of UL 478. First, you press against external covers and guards with a test tool having a spherical steel surface of 30-mm diameter, using a force of 250N. Next, you drop a 0.5-kg, 15-mm diameter sphere from a height of 1.3m onto the top and sides of the equipment.

TABLE A—IEC 950 DIELECTRIC-STRENGTH TESTS

VOLTAGE APPLIED BETWEEN	CLASS I	CLASS II
PRIMARY AND BODY	1250V	3750V
PRIMARY AND SELV SECONDARIES	3750V	3750V
PRIMARY AND NON-SELV SECONDARIES	1250V	1250V
SELV SECONDARIES AND BODY	NO TEST	NO TEST
NON-SELV SECONDARIES AND BODY	1250V*	2500V
SELV AND NON-SELV SECONDARIES	2500V	2500V

*APPLY 10 TIMES THE WORKING VOLTAGE, TO 1250V MAX.
NO TEST NEEDED IF SECONDARY OPERATES AT <30V RMS.

You drop a handheld unit in its worst-case orientation from a height of 1m onto a hardwood floor.

Finally, the equipment has to undergo a 70°C bake for seven hours. After the tests, the unit cannot have openings that permit contact with hazardous parts. In addition, you should not be able to pull the power-supply cord free from the housing, and the unit should show no compromise of its supplemental or reinforced insulation.

You'll encounter a number of IEC 950 performance tests for ensuring device safety. First, you run the device at 10% above and 15% below its rated voltage. During these tests, overload protection should not operate. Next, you test dielectrics by applying 50% of the voltages shown in **Table A** to the primary circuits. A fully loaded unit should not draw more than 110% of its rated current. Motor-operated equipment must start smoothly three times at 85% rated voltage.

In the IEC 950 abnormals test for motors, units with thermal or impedance protection run with locked rotors for 18 and 15 days, respectively. Motors with manual reset capability run through 60 cycles with locked rotors. Temperature increases cannot exceed 150 to 215°C. A similar abnormals test for transformers uses shorted secondaries and alternately opened and shorted primaries.

Finally, the IEC spec (as well as UL) places a limit of 0.5 mrad/hr of CRT x-ray emission; the spec also limits ozone concentrations to 0.1 ppm. You should take care when you design circuitry that can generate ozone (for example, high-voltage circuits), because this gas is heavier than air and can accumulate in pockets.

Most of the hazards associated with EDP equipment are directly related to the ac-supply connections; UL specs tightly regulate these connections.

20 kΩ. For secondary circuits with a rating lower than 100V, 200 VA, the necessary spacing is determined according to the results of a performance test.

Another important construction consideration is your grounding technique. UL grounding regulations apply mainly to Class I devices. Part of the shock protection in a Class I device comes from grounding all exposed metal. Ground wires must be green in the US and green-yellow in Europe. You must use a terminal to connect the ground line to the mandatory 3-wire plug, and you should secure this terminal to the equipment frame by a screw (or welded stud, nut, or lockwasher) that won't be removed during normal servicing. Don't rely on either hinges or conductive coatings to carry fault current.

Class II units are those encased in insulated housings; the case itself, rather than the grounded metal, serves as protective insulation. Double or reinforced insulation, or a minimum amount of through-air spacing, is required between any hazardous parts and the operator. **Table 3** lists the minimum spacings required for double-insulated Class II devices. In some instances, it's impossible to separate live parts from operator access by using through-air spacing and plastic. In these cases, an extra-thick section of plastic, which serves as reinforced insulation, is acceptable.

Devices that fall under the Class II category use a 2-wire ac line cord. If you use metal clamps for strain relief, you must provide a form of supplementary insulation at least 1/32 in. thick between the clamp and the cord's insulation. You should securely fasten the wire and use screws, along with lockwashers, so that loosening will not compromise the double insulation.

Class 2 circuits relax UL rules

In EDP and telecomm equipment, Class 2 circuitry operates from relatively low voltage and current levels, so it does not present a high risk of fire or shock; therefore, UL standards make Class 2 circuitry exempt from certain safeguards. You can install fuses in the power supply's secondary circuit to limit current to Class 2 levels. For supplies of 21.2V max, these fuses must have a rating of 5A max, and for supplies of 21.3 to 42.4V, they must have a rating of 3.2A max. UL specs can also dictate the use of an isolation transformer in the power supply. Transformers satisfying UL 1310 or 1411, or double-insulated transformers (or those with reinforced insulation) meeting UL 1485, are satisfactory.

Underwriters Laboratories considers Class 2 circuits so free of hazards that it finds operator access acceptable, provided that two levels of protection exist between hazardous voltages and points of possible operator access. You can meet this requirement by providing an interlocking mechanism or by ensuring that Class 2 circuits are separated from other hazardous areas by double insulation.

TABLE 3—SPACING FOR <125V CLASS II DEVICES

SPACING TYPE	IN.	MM
THROUGH-AIR OR OVER-SURFACE SPACING BETWEEN: LIVE PARTS AND INACCESSIBLE DEAD METAL	1/16	1.6
LIVE PARTS AND ACCESSIBLE DEAD METAL	1/8	3.2
LIVE PARTS AND INSIDE SURFACE OF SUPPLEMENTARY INSULATION (ENCLOSURE)	1/32	0.8
SPACING THROUGH INSULATING MATERIAL: SUPPLEMENTARY INSULATION	1/32	0.8
REINFORCED INSULATION	5/64	2.0

Motors and switches deserve special thought

You need to give special design-for-safety considerations to particular types of components such as motors, switches, and CRTs. Motor-related problems usually arise from locked rotors or from overheating during loaded conditions. To prevent these problems, you usually have to provide thermal-cutoff devices or impedance protection. In addition, motors should satisfy the individual safety standards, UL 519 and UL 547. Fuse ratings must not exceed 250% of the full-load current (300% for inductive loads). Switch ratings must equal or exceed the levels of their intended loads (200% for inductive loads), and the switches must disconnect all ungrounded connections.

In a system with motors of 1/3 hp or more, you are required to have a separate switch to control each motor. If you provide a convenience receptacle, it must be properly rated and wired—that is, its third wire must be grounded, and its silver lead must be connected to neutral. The receptacle should have a marking indicating the maximum output current. Finally, the receptacle should have its own fuse, in accordance with the National Electrical Code; examples are a cartridge-type fuse, such as that found in household wiring boxes, or a listed circuit breaker.

CRTs present two hazards: x-rays and implosion. First, a CRT must meet its own individual component-recognition standard, UL 1418. In addition, the projected area **(Fig 4)** of an enclosure opening through

which flying parts might reach the CRT must measure less than 0.2 sq in. The UL standard limits x-ray radiation to 0.5 mrad/hr, averaged over 10 sq cm at a distance 5 cm from the CRT. You must perform the radiation test with the controls set to their worst-case settings. It's also necessary to check for worst-case radiation by alternately opening and shorting components in the CRT's high-voltage circuitry.

UL standards also require that you affix several warning and cautionary labels to your equipment. In fact, the labels themselves must undergo UL component recognition under UL 969. Words such as "DANGER," "CAUTION," and "WARNING" must be typeset at least 3/32 in. high. In addition to the manufacturer's information, you must specify voltage, current, frequency, and a symbol for alternating or direct current on each label. Other types of labels are also required; two examples are "Operators or service personnel may come in contact with hot surfaces," and "Service personnel may be exposed to capacitors that won't discharge according to UL standards."

In general, the safety requirements described here are designed to protect an equipment operator; the

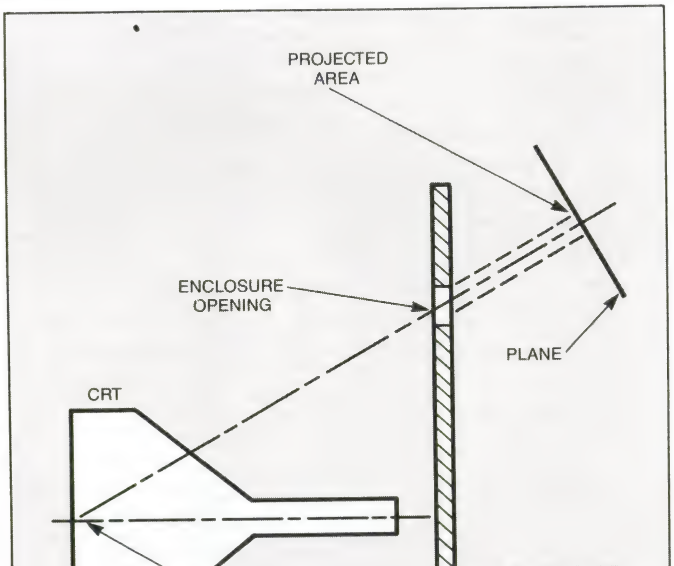

Fig 4—To prevent flying parts *from reaching a CRT, the projected area of enclosure openings must not exceed 0.2 sq in. The purpose of this requirement is to prevent implosion of the CRT.*

UL standards assume that a serviceperson is aware of potential hazards during equipment repair and maintenance. Nonetheless, some standards mandate the incorporation of protective measures for service people as well.

For example, if service personnel must reach over, under, or around uninsulated electrical parts or moving parts while a piece of equipment is energized, you must place all live parts that present shock or fire hazards in such a way that contact or bridging is unlikely during servicing. You have to make sure that power-supply capacitors discharge to less than 50V, 20J in 1 sec, or else provide service-personnel warning labels. You must also affix warning labels on parts that service personnel would expect to be at ground potential but are not, and on parts that can become energized by a single fault. If you use an interlocking mechanism as protection for a serviceperson, it must be capable of 6000 operations. This requirement is less stringent than that for equipment operators.

In addition to all these safety specs governing the construction of EDP equipment, UL specs cover a series of power-on performance tests. The first and simplest of these tests applies to a unit's current consumption and its power cables. The maximum current for any equipment must not exceed 110% of the rating on the equipment label. Strain reliefs attached to the unit's power cable must withstand a 35-lb pull from any angle; the UL standard does not allow for any movement of the power cable.

For purposes of fire prevention, the standard specifies the maximum temperature rise permitted for all components in a unit. The components list includes transformers, motors, relays, inductors, large electrolytic capacitors, switches, fuses, and pc boards under components that provide heat. For a typical test, you would mount a number of thermocouples at key positions where you'd expect the temperature to rise. You can find the maximum permitted temperature rise for various components in Table 32.1 of UL 478 (which is too voluminous to reproduce here). In addition to internal components, the UL spec stipulates the maximum temperatures of external surfaces **(Table 4)**.

Other tests are intended to evaluate the efficacy of insulation under electrical stress. Between the primary winding and ground or between the primary and secondary windings, you have to apply 1250V ac for one minute. Sudden, excessive current flow and cascading voltage drops indicate insulation breakdown—and failure. You have to apply the test voltages stipulated in

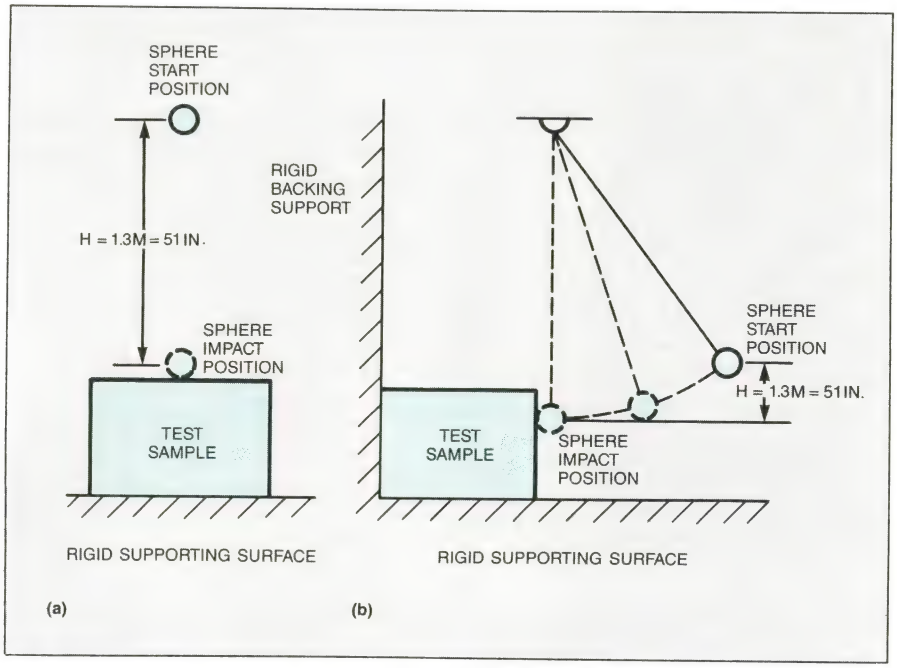

***Fig 5—Enclosures must be able to survive** contact with falling objects. In these tests for the top **(a)** and sides **(b)** of an enclosure, you drop a 2-in. steel sphere from a height of 51 in. The impact must not create openings that would permit the articulated probe of **Fig 2** to make contact with live parts.*

Table 5 from the secondary winding to ground or between multiple secondary windings.

Parts that either open or short-circuit in the primary circuit cause an anomaly called an "abnormal." These failures are capable of presenting a fire hazard, so UL 478 specifies a test for them. To perform the test, place the equipment over a hardwood surface covered with tissue paper, cover the unit with cheesecloth, and insert a 3A fuse in the ground return. The purpose is to determine the cause of a fire hazard, whether it be the failure of parts in the primary circuit, or whether it be a mechanical malfunction such as jammed components, wrongly set switches, or wrongly inserted connectors.

To test for abnormals, try all switch settings and initiate all possible jams of mechanical components. Further, alternately open and short each part in the primary circuit. Most of these abnormals will, in the worst scenario, simply cause the primary fuse to blow, and this result is acceptable. If the cheesecloth ignites or the 3A fuse in the ground return opens, the equipment is unacceptable. After each abnormal testing, the standard specifies that you perform a 1250V dielectric test between the primary winding and ground. Dielectric breakdown is considered unacceptable.

The UL spec also requires tests to verify that equipment won't tip or fall and cause operator injury. In one test, the unit must return to its starting position after being subjected to a 10° tilt. For this test, you can leave all doors on the unit closed, but you must place all casters and jacks in their most unfavorable positions.

If your equipment has any horizontal surfaces lower than 1m high, you must apply an 800N downward force to the surface to see if the unit will tip. For equipment taller than 1m and weighing more than 25 kg, apply a force equal to one-fifth the unit's weight (250N max) to points as high as 2m in every direction but up. Again, the equipment must not tip.

Another series of tests for mechanical integrity measures the equipment's reaction to impact. You have to drop handheld units onto a hardwood floor three times from a height of 3 ft. For other equipment, you have to drop a 2-in. sphere from a height of 51 in. onto the top and sides of the unit **(Fig 5)**. In another test for mechanical integrity, you have to press on the enclosure with a special tool that has a ½-in. steel sphere at its tip. For metallic enclosures, the pressing force is 111N; for nonmetallic enclosures, it is 30N.

Your equipment will fail these tests if any holes appear in the enclosure large enough to allow an IEC articulated probe to make contact with live parts. Distortions can appear, but these should not cause an enclosure to come in contact with hazardous parts or permanently reduce spacings to values less than those in **Table 2.**

Because many users interrupt the ground line by using adapters, the UL standard specifies the leakage

TABLE 4—MAXIMUM TEMPERATURES OF EXTERNAL SURFACES

SURFACE	METAL °C	METAL °F	NONMETALLIC °C	NONMETALLIC °F
HANDLES, KNOBS, OR SURFACES THAT ARE GRASPED FOR LIFTING, CARRYING, OR HOLDING	55	131	75	167
HANDLES OR KNOBS THAT ARE TOUCHED, BUT DO NOT INVOLVE LIFTING, CARRYING, OR HOLDING; SURFACES SUBJECT TO CONTACT DURING INTENDED USE OR MAINTENANCE	60	140	85	185
OTHER SURFACES	70	158	95	203

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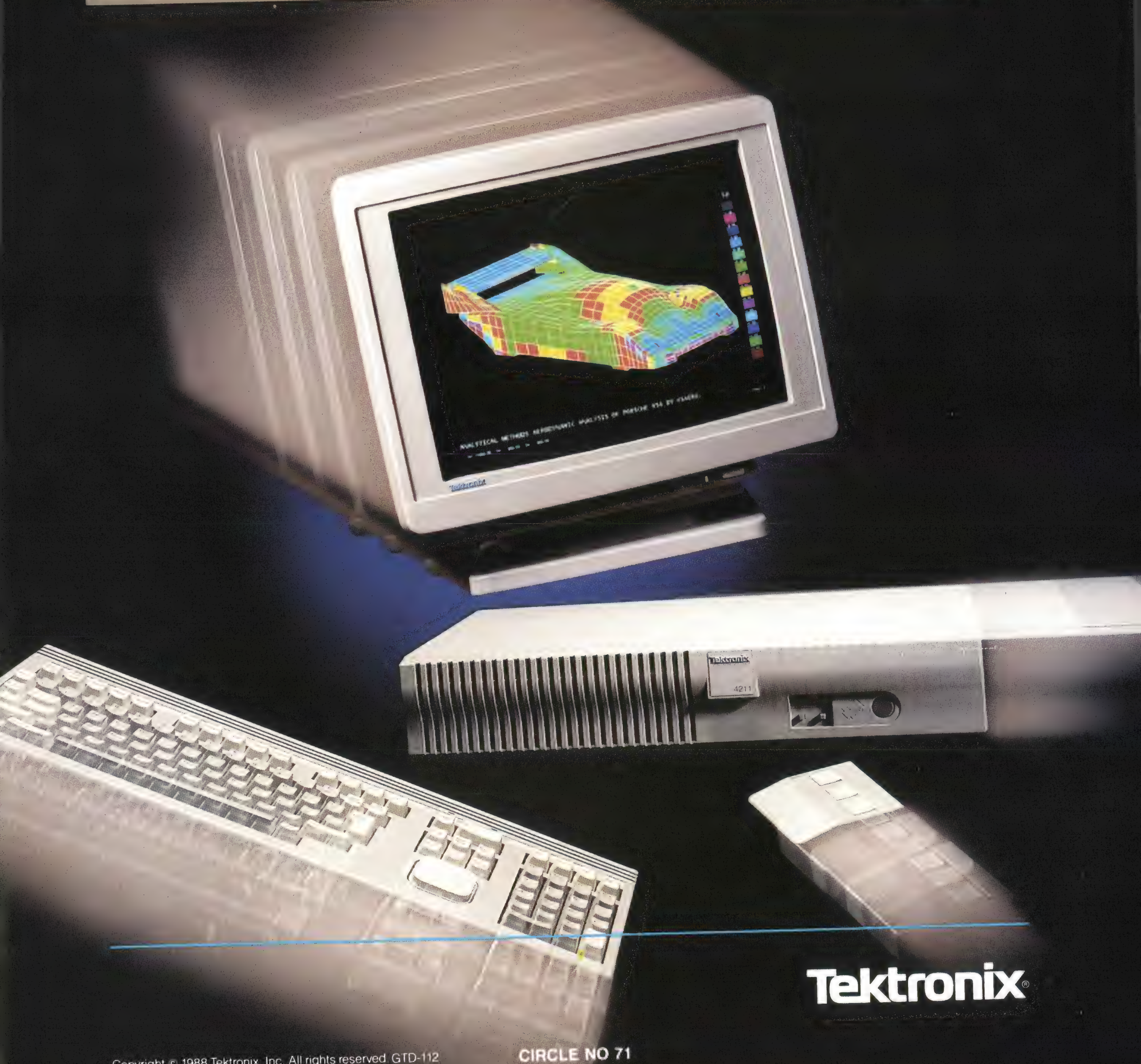

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Low-voltage and -current Class 2 circuits are exempt from fire and shock hazard testing, providing the components meet flame ratings.

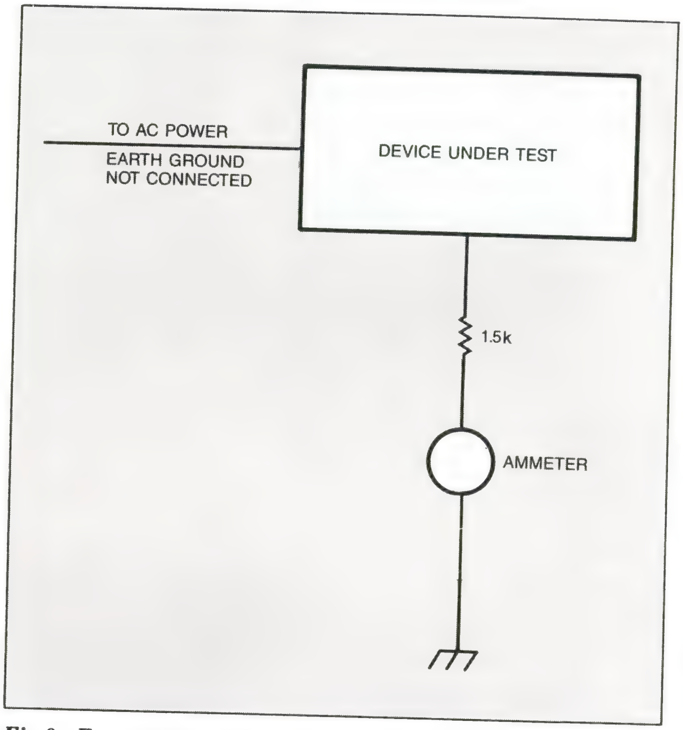


***Fig 6—For equipment with no earth-ground return,** you must test for leakage to ground. For such ungrounded equipment, the leakage to ground must not exceed 0.5 mA. If your equipment has a line filter, UL specs allow a maximum leakage of 5 mA.*

current that can flow to earth ground. **Fig 6** shows the test method. In this test, you break the ground line of the 3-wire line cord and measure the current from the enclosure's exposed metal to earth ground. Usually, UL standards stipulate that the leakage current must not exceed 0.5 mA. If your unit incorporates a line filter, the spec allows a ground-circuit current of 5 mA.

The leakage requirement for Class II devices is 250 μA max vs 5 mA for Class I units. Moreover, you must measure the insulation resistance; the UL limit is 7 MΩ min. If inaccessible dead metal exists in the enclosure, the resistance between the dead metal and the live parts must be 2 MΩ min. Between the inaccessible metal and the accessible surface, it must be a minimum of 5 MΩ. Before performing insulation tests, you must condition the equipment by exposing it to 99% relative humidity for 48 hours.

A final test necessary to satisfy UL performance requirements involves checking the motors connected to the secondary circuitry for fire hazards. This test, applicable to motors running at voltage and power levels lower than 100V, 200 VA, consists of locking the rotor at full power for seven hours. You have to place cheesecloth over the equipment under test; it must not ignite. For motors running at levels higher than 100V, 200 VA, you have to apply the test for primary-circuit abnormals. Motors in Class 2 circuits and stepping motors are exempt from the locked-rotor test.

TABLE 5—TEST REQUIREMENTS FOR SECONDARY CIRCUITS

VOLTAGE PRESENT IN CIRCUIT V RMS	V PEAK	TEST-VOLTAGE LEVEL
0 TO 30	0 TO 42.4	NO TEST REQUIRED
30.1 TO 333.3	42.5 TO 471.3	10 TIMES MAXIMUM VOLTAGE PRESENT IN CIRCUIT (1000V RMS MAX)
333.4 TO 1000	471.4 TO 1414	3 TIMES MAXIMUM VOLTAGE PRESENT IN CIRCUIT
1000 OR MORE	1414.1 OR MORE	1750V RMS PLUS 1.25 TIMES VOLTAGE PRESENT IN CIRCUIT

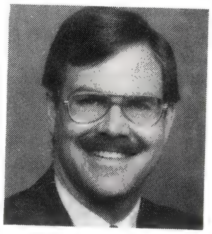
100% factory testing is required, too

All of these performance tests must, of course, be done on the sample units used in the evaluation and approval process. You should also be aware, however, that 100% factory testing is required for compliance.

EDN

Author's biography

Glen Dash is the founder of Dash, Straus & Goodhue Inc, a Boxborough, MA-based R&D organization that deals with various types of standards compliance. Glen holds a BSEE and an MBA, both from MIT, and a law degree from Harvard University. He enjoys playing softball in his leisure hours.



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DESIGNER'S GUIDE

op-amp feedback circuits Part 2

Bode plots enhance feedback analysis of operational amplifiers

*Bode plots graphically represent an op amp's gain, phase-margin, and noise characteristics. Part 1 of this series (**Ref1**) covered the feedback analysis of single-stage operational amplifiers; the conclusion examines the feedback behavior of composite op-amp circuits.*

Jerald G Graeme, *Burr-Brown Corp*

Whereas the normal op-amp feedback loop involves only one amplifier, designers oftentimes need to extend the feedback loop to work with composite circuits that use two or more op amps for increased gain. By adhering to conventional feedback principles, you can implement phase compensation for the extended loop and rely on a Bode plot to provide a visual representation of the increased gain and the opportunity for extended bandwidth.

For instance, with two op amps in the same loop as in **Fig 1,** you can achieve increased gain without incurring any added offset and noise error. The input-error effects of the second amplifier are divided by the open-loop gain of the first amplifier. The net open-loop gain of this composite circuit becomes the product of the individual op-amp gains and greatly reduces the overall gain error and nonlinearity.

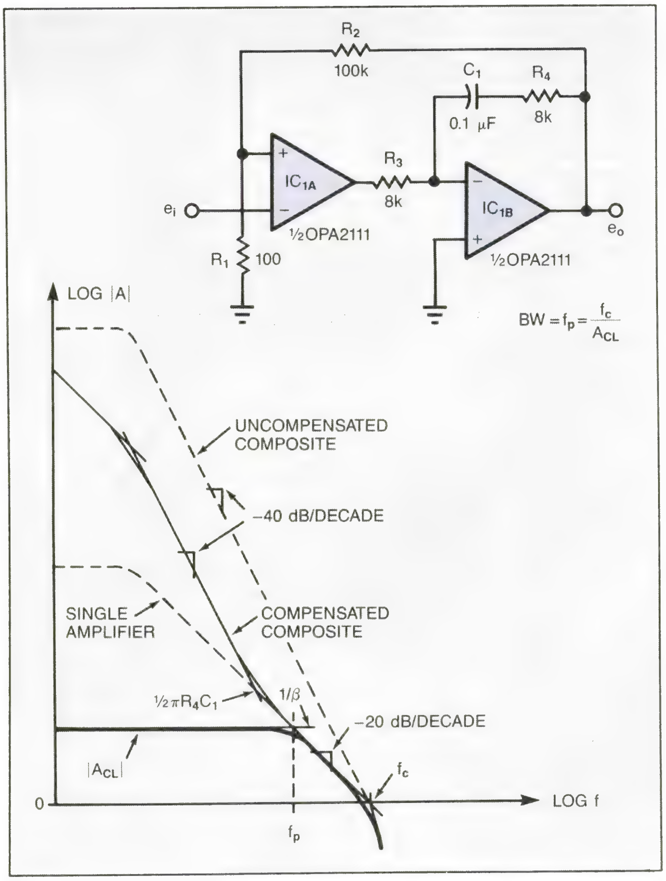

Fig 1—To utilize the boosted gain of the composite amplifier, *traditional phase-compensation techniques tailor the gain-magnitude slope to obtain a stable region with a 1/β intercept.*

With a composite amplifier, a designer can selectively optimize the performance characteristics of both the individual op amps and the overall circuit.

In **Fig 1,** the two op amps are those of the dual OPA2111, which imposes only a modest cost increase over a single device. You could, of course, select individual op amps to provide specific performance characteristics. In the latter case, you might select the input amplifier for good dc and noise performance and the output amplifier for its load-driving and slewing performance. For example, the output amplifier could handle the load current and the resulting power dissipation, thus producing no thermal feedback to the input of the composite circuit. Moreover, it could also fulfill the high-slew-rate demands of the application. The input amplifier in this case would only swing through small signals.

Extending the dynamic range is feasible

An integrator and a common op-amp test loop can demonstrate the benefits of using a composite amplifier. By extending the composite open-loop gain to higher levels, you can expand the dynamic range for integrating analog functions. The low-frequency intercept moves back by a factor equal to the added amplifier gain. This change is so extreme that other error effects will surface well before the gain error from the intercepts. For two op amps in the same loop each having 100-dB open-loop gain, the composite gain is 200 dB. At this gain level, an input error of 1 nV will develop the full 10V output swing. Long before the circuit reaches that limit, noise becomes a prime ac constraint and typically restrains lower-level accuracy over a dynamic range of about 3,000,000:1. Nevertheless, this restraint is a 30:1 improvement over a single op amp and moves the focus of measurement accuracy to other factors.

In the op-amp test-loop application **(Ref 2)**, the addition of the second amplifier removes signal swing from the output of the tested device. The extra gain transfers that voltage swing to an isolated output and removes any gain error from the signal detected at the tested amplifier's inputs. This gain-error removal permits the discernment of other input-error signals for the measurement of parameters such as power-supply and common-mode rejection. If these parameters were to approach the level of the amplifier's open-loop gain, gain-error signals at the input would cloud the effects of the measured parameter.

With a composite op-amp structure, you must include the roll-off characteristics of both amplifiers in your ac analysis and have some means of providing phase compensation for the loop. Two op amps in a common loop invite oscillation; the individual amplifier poles combine for a composite 2-pole roll-off. As shown in **Fig 1,** the logarithmic scale makes the initial composite-response curve the linear sum of the two individual responses. The upper, dashed response curve, which has a -40-dB/decade slope, shows this result.

Two methods are available for compensating the composite loop. One modifies the gain-magnitude response and the other alters the $1/\beta$ curve. The more usual of the two approaches is to reduce the slope of the gain-magnitude curve in the vicinity of the intercept—as **Fig 1** does. After forcing the compensated response to roll off earlier, the gain-magnitude curve returns with a more gentle slope to the boundary of the uncompensated response. This action serves the general-purpose requirements of voltage-gain applications and produces a stable range that you can place almost anywhere in the total composite-gain range.

Fig 1 achieves this compensation by creating a modified integrator response for IC_{1B}. Because this integrator is an inverting circuit, the inputs of IC_{1A} are reversed to retain only one phase inversion in the loop. Capacitor C_1 blocks the local dc feedback, and the overall gain is still the product of the two open-loop gains. The integrator response that R_3 and C_1 established for IC_{1B} rolls off this composite gain. Next, the first open-loop pole of IC_{1A} returns the compensated response slope to -40 dB/decade. At a higher frequency, a response zero provides the region of reduced slope thanks to the inclusion of R_4. Above the break frequency of R_4 and C_1, R_4 transforms the response of IC_{1B} from an integrator to an inverting amplifier with a gain of $-R_4/R_3$.

Where this gain is unity, the compensated response drops to and follows the open-loop response of IC_{1A} as shown. For gain levels other than unity, you have different options, which you can explore by using other response plots and defining the particular stable conditions you have in mind. Having control of this gain becomes particularly useful as the $1/\beta$ intercept approaches the uncompensated unity-gain crossover point. In this region, the second poles of the two op amps increase the phase shift. In such cases, you have to make the magnitude of the internal R_4/R_3 gain less than unity to force the compensated response to cross over earlier. Generally, when you have two op amps of the same type, making $R_4 = R_3/3$ will yield a unity-gain stable composite amplifier.

The net phase correction that you can achieve with this technique depends on the frequency-response

range for which you maintain the -20-dB/decade slope. This span begins with the R_4C_1 break frequency and ends with the intercept of the composite open-loop response. After this intercept, the lack of open-loop gain returns the response to that of the uncompensated composite amplifier. To ensure a phase margin of 45° or more, you can use the guidance that the Bode phase approximation provides; the plot shows that this reduced slope region must last for three decades of frequency and must intercept the $1/\beta$ curve after running for at least a decade.

Extending the bandwidth may be desirable

Although most engineers are familiar with this type of phase compensation, it is too restrictive of bandwidth at higher gains. For applications requiring higher gains, you can greatly extend the bandwidth and reduce the settling time by 40:1 by using a different phase-compensation technique. The general-purpose $R_4 = R_3$ case of **Fig 1** sets a constant closed-loop gain-bandwidth product. Looking at the curves, you can see that the closed-loop bandwidth is the same as that for IC_{1A} itself when $BW = f_p = f_c/A_{CL}$. Even so, the large separation between the compensated and uncompensated responses shows a significant sacrifice in bandwidth—expressly for the accommodation of phase compensation. Uncompensated, the gain-magnitude response has a gain-bandwidth product that increases with closed-loop gain and that provides a potential bandwidth of $f_p = f_c \backslash \sqrt{A_{CL}}$. Comparing the last two expressions shows that the potential for bandwidth improvement equals $\sqrt{A_{CL}}$, which is significant at higher gains.

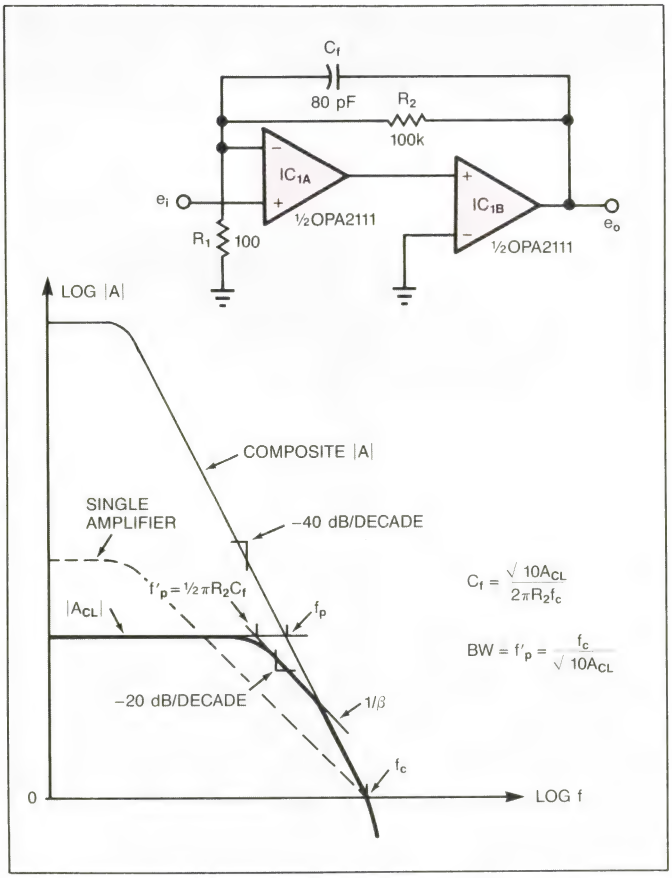

*Fig 2—**For greater bandwidth in high-gain circuits,** you can provide phase compensation for the $1/\beta$ response to retain a smooth open-loop response for fast settling.*

Another way is to compensate the $1/\beta$ curve

You can take advantage of quite a bit of this bandwidth-improvement opportunity by compensating the $1/\beta$ curve instead of the gain-magnitude response curve. By referring back to the rate-of-closure stability criteria discussed in Part 1 (**Ref 1**), you would see that both curves contribute to the rate-of-closure parameter even though the gain-magnitude curve is generally the focus of phase-compensation efforts. To satisfy the rate-of-closure criteria, all that is necessary is to control the difference between the slopes, regardless of the slopes of the individual curves. So, instead of reducing the gain-magnitude slope, increase the $1/\beta$ slope (**Fig 2**). A simple capacitive bypass of feedback resistor R_2 accomplishes this slope increase for a final 20-dB/decade rate-of-closure. An integrator configuration, on the other hand, with its special characteristics, inherently produces the -20-dB/decade slope for $1/\beta$ and achieves optimum bandwidth and dynamic range.

From a phase-shift perspective, this alternative approach to compensation adds phase shift to $1/\beta$ instead of subtracting it from the gain-magnitude response. It pushes the net phase shift beyond 180° toward 270°, rather than pulling it back toward 90°. In either case, the resulting phase margin approaches 90°, but the **Fig 2** method is simpler and achieves greater bandwidth. The pole created with C_f sets the bandwidth instead of the $1/\beta$ intercept.

Two factors distinguish this feedback-factor compensation technique for higher gains. Greater bandwidth is open for reclaiming, and the associated $1/\beta$ curves are well above the unity-gain axis. From higher levels, the $1/\beta$ roll-off is developed well before its intercept with the gain-magnitude curve. Starting this roll-off a decade ahead of the final intercept produces a 45° phase

Two methods are available for compensating the composite feedback loop. One modifies the gain-magnitude response, the other alters the 1/β curve.

adjustment for a like amount of phase margin. The slopes of the two curves show that, in order to accomplish this phase adjustment, C_f must break with R_2 one-half decade below the initial intercept frequency, f_p. Then, the 2:1 difference in slopes will place the new intercept one-half decade above f_p for the required full decade of the 1/β roll-off.

Time to brush up on equations

Again, the design equations for the required value of C_f and the resulting bandwidth are obvious from the logarithmic nature of the frequency axis. Setting f_p' at one-half decade below f_p implies that

$$\text{Log } f_p' = (\text{Log } f_p + \text{Log } f_p/10)/2,$$

for which $f_p' = f_p/\sqrt{10}$. From before, you'll remember that $f_p = f_c/\sqrt{A_{CL}}$ describes the uncompensated curve's bandwidth. The compensated bandwidth is

$$BW = f_p' = f_c/\sqrt{(10A_{CL})}.$$

Here, f_c is the unity-gain crossover frequency of the composite gain-magnitude response. As becomes obvious when you examine this expression, the improved bandwidth falls short of the total potential by $\sqrt{10}$. However, it is better than the **Fig 1** result by $\sqrt{(A_{CL}/10)}$, or a factor of 10, for a gain of 1000. Setting C_f to break with R_2 at f_p' defines the value of this capacitor as

$$C_f = \sqrt{(10A_{CL})}/2\pi R_2 f_c.$$

For the op amps of the dual OPA2111 shown, the gain-of-1000 bandwidth becomes 20 kHz as compared with the 2 kHz you'd realize if you used just one of the op amps.

Improving the settling time

Settling time also improves when you choose the composite amplifier's 1/β curve for phase compensation. The improvement is a result of both the increased bandwidth and the retained constant gain-magnitude slope. For a single amplifier of the OPA2111 type, for a gain of 1000, the settling time would be 700 μsec to 0.01%. Because the **Fig 2** amplifier has 10 times the bandwidth of a single amplifier, the settling time drops by the same factor to 70 μsec. This improvement would not be possible without the smooth and continuous slope of the compensated-amplifier response. A response having an intermediate pole and zero such as **Fig 1** does has low-frequency response terms that are slow to settle following a transient. Known as an integrating frequency doublet, this pole/zero combination is notorious for its poor settling time **(Ref 3)**. By providing phase compensation for the 1/β curve, you ensure that the smooth gain-magnitude curve is left undisturbed, therefore achieving the optimum settling time.

At lower gains, the benefit of the 1/β compensation technique diminishes as does its control of phase. Because lower gains have 1/β curves closer to the unity-gain axis, they have less room for 1/β roll-off. To produce an intercept with the gain-magnitude curve after a decade of 1/β roll-off requires a minimum closed-loop gain of 10. Op-amp phase shifts impose further limits by growing from 90° to 135° as they approach the unity-gain crossover frequency. In the practical case, this phase-compensation method needs gains of 30 or more for good stability.

This type of phase compensation does have an unusual aspect: Too great a compensating capacitance will have a surprising effect. Whereas increasing such capacitance normally yields more damping and a more stable response, making C_f too large will cause instability. As C_f increases, the resulting intercept moves toward f_c and encounters the added phase shift of the secondary-amplifier poles. Even greater values of C_f will drop the 1/β curve to its limit at the unity-gain axis. From there, it proceeds along the axis to the magnitude-curve intercept that guarantees oscillation. Only a range of compensation-capacitor values provides stability with this second approach; the 1/β curves display this range for sensitivity-analysis purposes. Because of the capacitor's window of stable values, a random selection of C_f followed by a stability test is likely to miss the bandwidth opportunity of this technique.

Phase shift and stability come next

Another concept fundamental to op-amp feedback in composite-amplifier circuits becomes apparent when you examine phase shift and stability. Composite amplifiers such as the one in **Fig 3** produce a −40-dB/decade slope over wide ranges both before and after the 1/β intercept. Because this slope corresponds to a 180° phase shift, frequent concern over stability conditions arises at points other than that of the critical intercept. Beyond the 1/β intercept, the loop gain is

less than 1 and therefore it is easy to see that the circuit cannot sustain oscillation. Yet, prior to the intercept, the gain of the feedback loop is very high and would seem capable of causing the circuit to oscillate.

In reality, the high loop gain is a protection against, rather than a promoter of, oscillation. Sustained oscillation depends on the op amp's gain-error signal. In **Fig 3,** the gain error, e_o/A, appears between the op-amp inputs and receives amplification from the closed-loop gain, A_{CL}. Here, A_{CL} is that of the noninverting configuration, the noise gain that reacts with any input-referred error signal. To sustain oscillation, the amplified error signal must independently deliver the output signal. This action requires that $(-e_o/A)A_{CL}=e_o$. Note that e_o appears on both sides of this equation; it should therefore be obvious that any solution must conform to very specific constraints. This equation expresses both polarity and magnitude constraints; the composite amplifier's 180° phase shift satisfies the sign change.

For the magnitude constraint, two possible solutions exist. The first is $e_o=0$, which is the stable state for

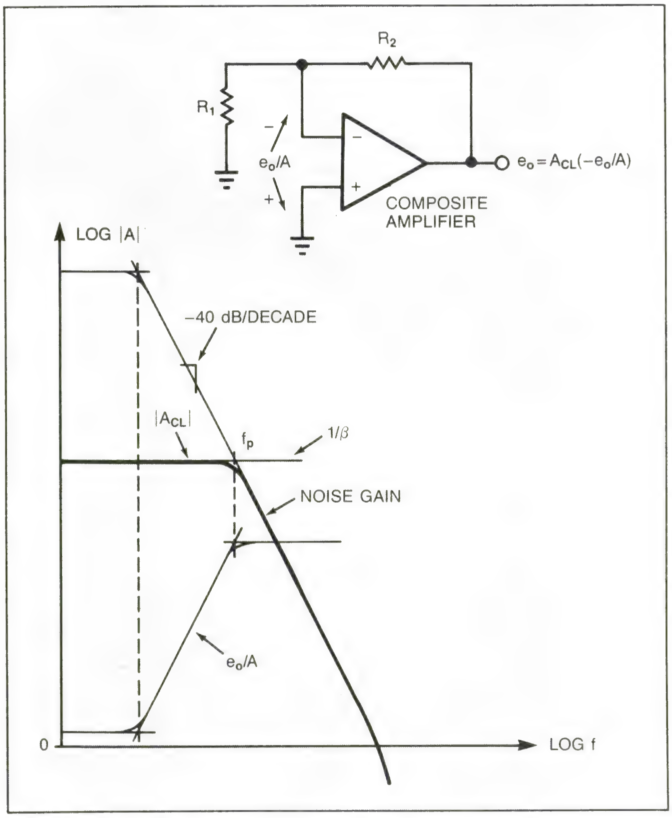

Fig 3—A phase shift of 180° causes oscillation *only where the gain-error, e_o/A, is capable of independently supporting the output signal.*

the composite amplifier in the questioned region. There, the loop gain makes the signal e_o/A too small to independently support an output signal. In the plots of **Fig 3,** e_o/A starts at a very low level due to the high loop gain at low frequencies. As you move up in frequency, the gain-error signal rises while the amplifier-response slope signals its polarity inversion through the 180° phase shift. This inversion increases the output signal but cannot sustain it until the gain-error signal reaches a sufficient level. This critical level is a prerequisite for oscillation.

This level applies to the second solution for the magnitude constraint. At this level, A/A_{CL} has unity magnitude and maintains the balance for the previous feedback equation's magnitude requirement. Unity loop gain occurs at the $1/\beta$ intercept where the open-loop and noise-gain curves meet. Without phase-compensation intervention, this intercept satisfies both the phase and magnitude requirements for oscillation. Beyond this point, e_o and A fall off together, leaving the e_o/A signal constant and unable to support oscillation with the reduced gain. At the point where the magnitude of the gain error and the feedback phase shift must both reach specific levels to support oscillation, the intercept becomes critical. Before or after the intercept, the loop phase shift can be at any level and the gain-error magnitude will not be sufficient to cause instability.

Unfortunately, despite the composite amplifier's very specific requirements for oscillation, the greatly varied applications of op amps make this critical condition all too easy to encounter. To contend with this problem, you can rely on the $1/\beta$ curve to present a visual prediction of the problem and provide insight into a solution.

Variable feedback helps

Some applications demand that you include a second active element in the feedback loop to produce a varying feedback factor. In these applications, both the magnitude and the frequency characteristics of $1/\beta$ become variables. Fortunately, the gain- and feedback-response curves offer a means of quickly evaluating the range of conditions resulting from the changing feedback.

The most common way to provide magnitude variation in the feedback factor is to use a low-cost analog divider realization. Placing a multiplier in the feedback loop of an op amp **(Ref 4)** makes feedback a function of a second signal and therefore produces divider opera-

Various phase-compensation techniques are available to tailor the circuit's bandwidth and settling time.

tion. With signal-dependent feedback, the bandwidth and stability conditions also become variables.

Fig 4 shows the divider connection and demonstrates the effect of voltage-controlled feedback on 1/β. The amplifier's feedback inverts the function of the multiplier by placing the feedback signal under the control of the e_2 signal. Then, the multiplier's transfer function of XY/10 delivers $e_o(e_2/10)$ to R_2. This action scales the feedback signal by comparing e_2 to a 10V reference level to obtain

$$\beta=(e_2/10)R_1/(R_1+R_2).$$

With the feedback factor under control of this signal, the 1/β curve moves across the full range of the gain-magnitude response. As e_2 nears zero, the 1/β curve approaches infinity, leaving the op amp essentially in an open-loop configuration. At the other extreme, a full-scale 10V value for e_2 delivers a feedback signal to R_2 that equals e_o almost as if the multiplier were not present. Then, the net response is that of a simple inverting amplifier with a feedback factor of $R_1/(R_1+R_2)$ and an inverting gain of $-R_2/R_1$.

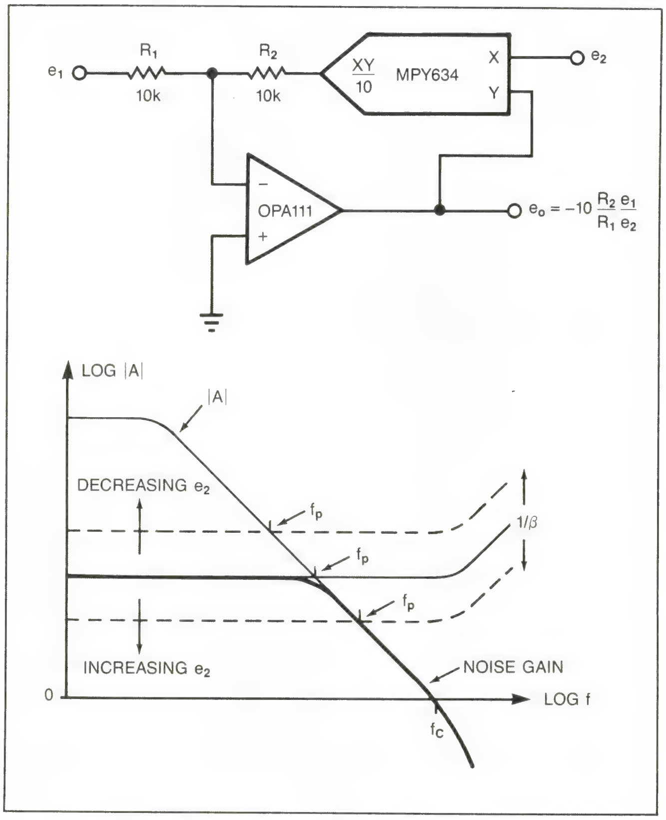

***Fig 4—For this common analog divider,** a variable feedback magnitude allows a range of conditions that define bandwidth and stability.*

From one extreme to the other

Between the extremes, the variation of e_2 moves the 1/β curve from as low as the unity-gain axis to above the upper reaches of the amplifier's gain-magnitude curve. This variation moves the critical intercept and requires attention to the rate-of-closure over the entire span of the gain-magnitude response. If no significant multiplier phase shift exists, the feedback will always resemble that of an inverting amplifier for a zero 1/β slope, and you can ensure stability by just using a unity-gain-stable op amp. You can then read the range of bandwidth for the divider operation directly from the moving 1/β intercept. For a given e_2 range, the intercept moves linearly with the signal, defining the corresponding bandwidth range.

The multiplier also introduces phase shift that alters the net phase shift around the feedback loop. Poles in the response of the multiplier circuit are zeros in the inverse 1/β function, causing the curve to rise at high frequencies. This rise moves toward the critical intercept when the multiplier control voltage, e_2, increases. This rise has an impact on the rate-of-closure, and the op amp must introduce a dominant pole to maintain stability. For the components shown, the OPA111 dominates the circuit roll-off because of its 2-MHz unity-gain crossover frequency. This frequency is well below the 10-MHz bandwidth of the MPY634 multiplier, placing the op amp in control. Other options that use a separate feedback path to restrict the op-amp bandwidth are also available **(Ref 5).**

Signal control of frequency characteristics

Other ways of providing variable feedback are also available. For example, you can have the signal control the frequency—rather than the magnitude—characteristics of the feedback. The result is a variable slope at the intercept, as is the case with the voltage-controlled lowpass filter in **Fig 5.** The basic elements of the lowpass filter are the op amp, the resistors, and the capacitor. If you replace the multiplier with a short circuit, these elements form a fixed-frequency roll-off. Essentially, this shorted condition is established when $e_2=10V$ and when the gain through the multiplier is unity. Capacitor C_1 then breaks with R_2 to define the filter roll-off just as if the resistor and capacitor were directly in parallel.

For levels of e_2 below full scale, the multiplier serves

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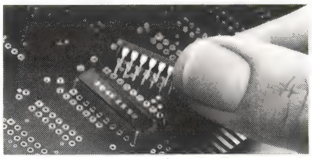

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CIRCLE NO 10

When you use a second active element in the feedback loop, both the magnitude and frequency characteristics of 1/β become variables.

as a voltage-controlled attenuator to effectively alter the filter time constant. Attenuating the feedback voltage to R_2 lowers the signal current to the summing node, which has the same effect as increasing the resistor's value. Increased effective resistance corresponds to a decrease in the resistor's break frequency with C_1. This break defines the variable filter roll-off when

$$f_p = e_2/20\pi R_2 C_1.$$

The maneuvering of the 1/β curve through this operation deserves closer inspection. The circuit exhibits a signal-dependent transition between the two different loops, which alternately controls the feedback. At low frequencies, C_1 is effectively an open circuit, and the controlling feedback path is through the op amp and the multiplier. This composite structure has resistive feedback that defines a signal gain of $-R_2/R_1$ and a noise gain of $(R_1+R_2)/R_1$. The latter relationship equals 1/β at low frequencies and the curve of interest starts at this level with a zero slope. At the high-frequency end, the composite structure is overridden when C_1 acts as a short circuit, which results in a unity feedback factor around the op amp. This short circuit absorbs all feedback current from R_2 without any corresponding change in the amplifier output voltage. The feedback loop of the composite structure is then disabled, switching feedback control to just the op amp. With C_1 then providing a unity feedback factor to the op amp, the 1/β curve follows the unity-gain axis at high frequencies.

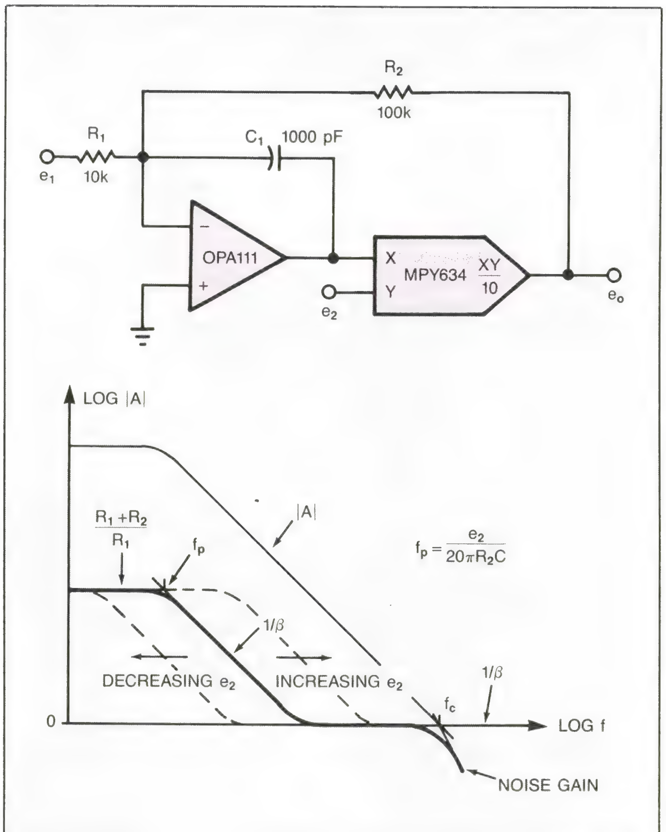

***Fig 5—In this filter circuit,** variations in the frequency characteristic of 1/β make possible a changing 1/β slope at the intercept.*

Once the 1/β levels are fixed at the extremes, the multiplier determines the nature of the transition between the two. In the transition region, feedback currents from R_2 and C_1 compete for control of the summing node of the op-amp input. The contest for dominance is analogous to the frequency-dependent control of impedance with a parallel RC circuit. In both cases, the 3-dB point, where each element carries the same magnitude of current, defines the transition of control. The **Fig 5** filter achieves equal element currents when the impedance of C_1 and the effective impedance of R_2 are equal. This equality defines the voltage-controlled roll-off frequency of the filter as previously expressed. At this frequency, 1/β also rolls off and drops at −20 dB/decade to the high-frequency limit of the unity-gain axis.

What about controlling circuit stability?

The stability conditions of the **Fig 5** circuit depend on the particular feedback loop or the combination of elements that are in control at the intercept point. For the lower-frequency filter cutoff frequencies illustrated, the op amp's bypass capacitor takes control before the intercept and defines the relevant feedback conditions. Because the 1/β curve follows the unity axis at the upper end, you can guarantee stability by ensuring that the op amp be unity-gain stable. For higher-frequency cutoff frequencies, the 1/β transition moves toward the gain-magnitude curve of the op amp. Circuit response cannot move beyond this limit, so the op-amp roll-off becomes the upper boundary of filter operation.

When the cutoff frequency approaches this boundary, the intercept rate-of-closure varies, prompting stability analysis. First, the zero of the 1/β curve approaches the intercept, where it increases the slope of the curve. Because this action reduces the rate-of-closure, stability is improved and a more detailed analysis is unnecessary. A continued increase in the cutoff frequency moves the 1/β curve further to the

right where its pole interacts at the intercept. This break frequency returns the rate-of-closure to 20 dB/decade, thus retaining stability. Beyond this point, the intercept occurs at the flat lower end of the 1/β curve, and no further change in the rate-of-closure takes place.

Utilizing these various feedback conditions and a unity-gain-stable op amp, you can design a composite circuit that fulfills its primary stability requirement over the entire operating range. In addition, however, you may sometimes require a multiplier having a bandwidth much greater than that of the op amp, as the two previous examples demonstrate. Without a wide-bandwidth multiplier, 1/β would begin to rise near the higher-frequency intercepts and increase the rate-of-closure. The OPA111 avoids this complication when using the MPY634 multiplier by maintaining a dominant op-amp pole.

Other applications may involve feedback peaking and op amps that are not unity-gain stable—log amps and active filters, for example. For these and other variations requiring feedback analysis, the test remains the same. Look for the critical condition where the rate-of-closure is 40 dB/decade. Where conditions approach this level, conduct further analysis and compare phase-compensation alternatives for optimization. **EDN**

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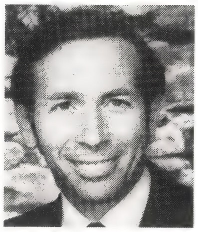
Author's biography



Jerald G Graeme is manager of instrumentation-components design at Burr-Brown Corp (Tucson, AZ), and directs a linear-IC development group. He holds a BSEE from the University of Arizona and an MSEE from Stanford University. Jerry has eight patents to his credit. His leisure pursuits include photography, woodworking, and scuba diving.

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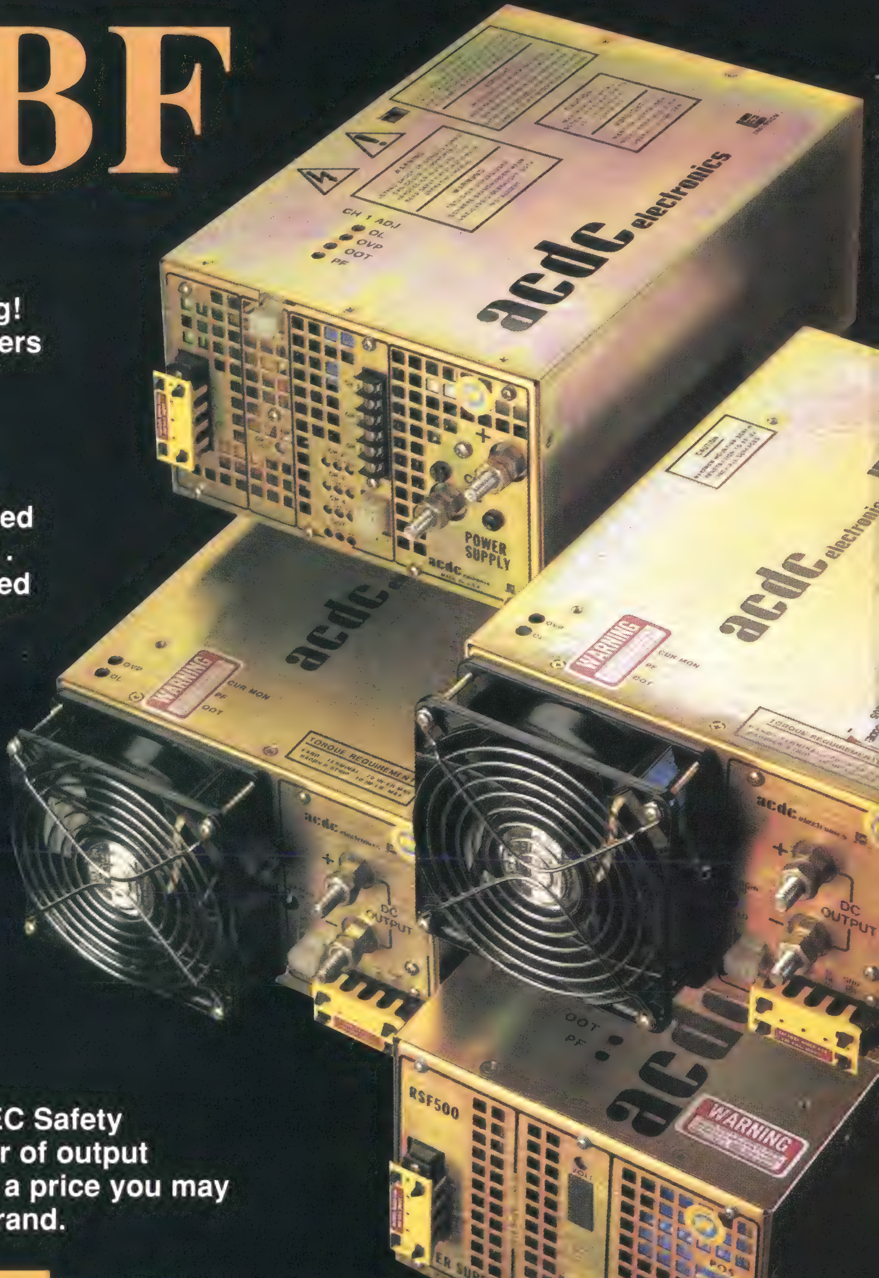

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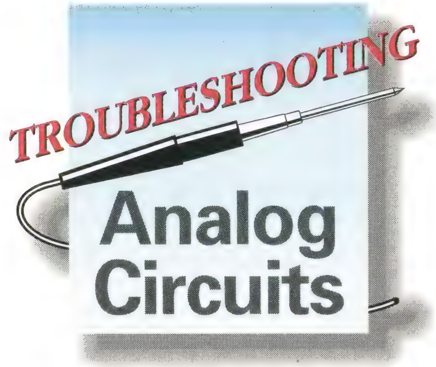

PART 3

Troubleshooting gets down to the component level

In recent issues, this series has covered the philosophy of troubleshooting analog circuits and the tools and equipment you need to do so. But if you're working on a circuit and are not aware of what can cause component failure, finding the root of your problem could be difficult. Hence, this installment covers resistors, inductors, and transformers; their possible modes of failure; and the unsuspected problems that may occur if you use the wrong type of component. Capacitors will be covered in the next installment.

Robert A Pease, *National Semiconductor Corp*

Troubleshooting circuits often boils down to finding problems in passive components. These problems can range from improper component selection in the design phase to damaged components that hurt the circuit's performance. Resistors, inductors, and transformers can each be a source of trouble.

Resistors are certainly the most basic passive component, and, barring any extreme or obscure situations, you won't usually run into problems with the parts themselves. I don't mean to say that you'll never see any problems, but most of them will be due to the way you use and specify resistors. In other cases, some other part of the circuit may be causing damage to a resistor, and the failure of the resistor is just a symptom of a larger problem.

You may eventually have to track down a wide variety of problems involving resistors to achieve a working design. Some will seem obvious. For example, your circuit needs a 10-kΩ resistor. The technician reaches into the drawer for one and instead gets a 1-kΩ resistor, which then mistakenly gets inserted into your board. This example illustrates the most common source of resistor trouble in our lab. Consequently, I ask my technicians and assemblers to install resistors so that their values are easy to read.

Sometimes a resistor gets mismarked; sometimes a resistor's value shifts due to aging, overheating, or temperature cycling. Recently, we found a batch of metal-film resistors whose values had increased by 20 to 900% after just a few dozen cycles of −55 to +125°C. As it turned out, our QC department had okayed only certain resistors to be used in burn-in boards, and these particular resistors had not been okayed.

Resistor characteristics can vary widely

You should be familiar with the different resistor types in order to select the most appropriate type for your application; the most common types and some of their characteristics are summarized in **Table 1.** A component type that's good for one application can be disas-

Transformer problems can be due to an incorrect turns ratio or an incorrect winding polarity.

TABLE 1—TYPICAL RESISTOR CHARACTERISTICS

RESISTOR TYPE	RANGE* (Ω)	TC (±PPM/°C)	PARASITIC EFFECTS	COST
COMPOSITION	1–22M	HIGH	LOW	LOW
METAL FILM	10–1M	LOW	MEDIUM	MEDIUM
CARBON FILM	10–10M	MEDIUM	MEDIUM	MEDIUM
WIREWOUND	1–273k	LOW	HIGH	HIGH
THIN-FILM	25–100k	LOW	LOW	MEDIUM
THICK-FILM	10–1M	LOW	LOW	MEDIUM
DIFFUSED	20–50k	HIGH	HIGH	LOW

*RANGE MAY VARY BY MANUFACTURER.

trous in another. For example, I often see an engineer specify a carbon-composition resistor in a case where stability and low TC are required. Sometimes it was just a bad choice, and a conversion to a stable metal-film resistor with a TC of 100 ppm/°C max considerably improves accuracy and stability. In other cases, the engineer says, "No, I tried a metal-film resistor there, but, when I put in the carbon resistor, the overall TC was improved." In this case, the engineer was relying on the carbon-composition resistor to have a consistent TC. I have found that you can't rely on consistent TC with the carbon-composition type, and I do not recommend them in applications where precision and stability are required.

However, carbon-composition resistors do have their place. I was recently reviewing a military specification that spelled out the necessary equipment for the ESD testing of circuits. An accurate 1500Ω resistor was required for use as the series resistor during discharge of the high-voltage capacitor. In this case, you would assume that a metal-film resistor would be suitable; however, a metal-film resistor is made by cutting a spiral into the film on the resistor's ceramic core **(Fig 1a)**. Under severe overvoltage conditions, the spiral gaps can break down and cause the resistor to pass a lot more current than Ohm's Law predicts—the resistor will start to destroy itself. Therefore, the spec should have called for the use of a carbon-composition resistor, whose resistive element is a large chunk of resistive material **(Fig 1b)**. This resistor can handle large overloads for a short time without any such flashover. Even when you are applying a 200 to 400%

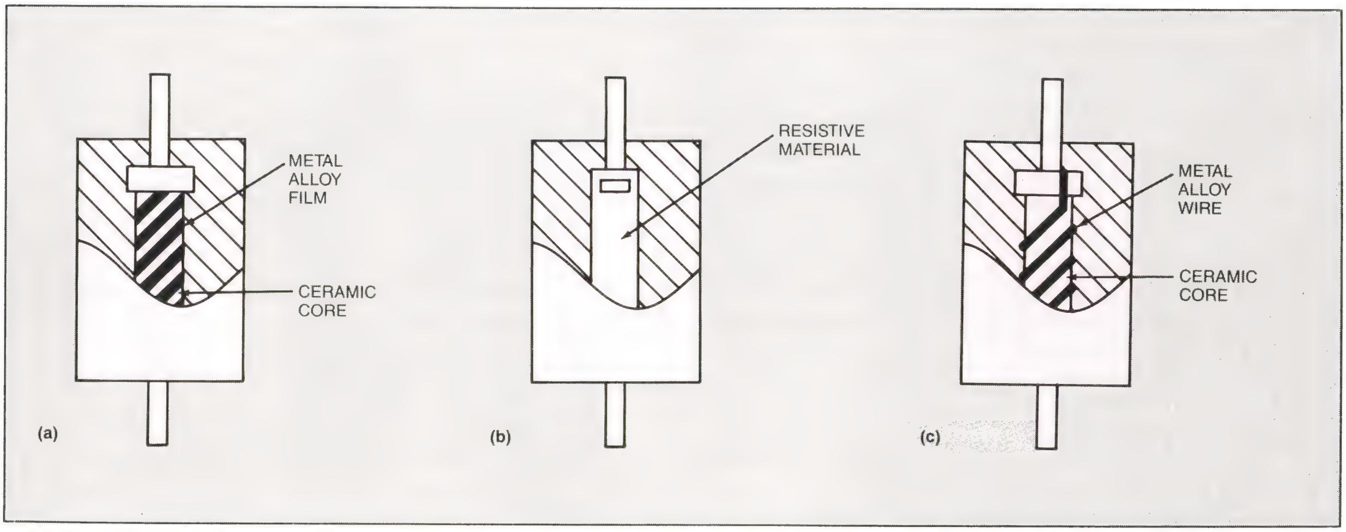

***Fig 1—Film resistors (a) are made by cutting a spiral into a layer of metal or carbon** deposited on a nonconductive core. Carbon composition types **(b)** have a solid core of resistive material; wirewound resistors are formed by winding resistive wire on a nonconductive core **(c)**.*

overload for just a short time, the nonuniform heating of the spiralled section of a metal-film resistor can cause the resistor to become unreliable. You can get around this problem by using a series connection of metal-film resistors. If you put fifteen 100Ω, ¼W metal-film resistors in series, an individual resistor would not see overvoltage or excessive power.

Carbon-film resistors are now quite inexpensive and have become the most common type of resistor around most labs. Their main drawback is that they are very similar in appearance to metal-film resistors and have some similar characteristics: Carbon-film resistors have 1% tolerances, are normally manufactured with spiral cuts, and have the same kind of voltage-overload limitations as metal-film types. But, carbon-film resistors have much higher TCs—500 to 800 ppm/°C. It's easy to mistakenly substitute a drifty carbon-film resistor for the intended metal-film type. Don't confuse the two.

Precision-film resistors, on the other hand, are available with greatly improved accuracy and TC. Compared to ordinary RN55D and RN55C resistors with TCs of 100 or 50 ppm/°C, these resistors have TCs as good as 20, 10, 5 or 2 ppm/°C and accuracies as good as 0.01%. These resistors are comparable to small precision wirewound resistors but are generally smaller and less expensive. They also have less inductance than the wirewound types and, thus, are suitable for higher-speed operation. A few spirals on a film substrate add negligible inductance compared to the hundreds or thousands of turns on a wirewound resistor's bobbin. Precision-film resistors are also available in matched sets of discrete resistors whose relative accuracy and TC tracking are better than those of individual resistors.

You can also buy custom thin-film resistor networks on a single substrate if your requirements are critical. A more economical route is to use four, seven, or eight matched precision thin-film resistors in a DIP. I have found the TC tracking of these devices from several manufacturers to be better than 1 ppm/°C. These sets are ideal for precision amplifier stages and DACs. Also, when you buy resistors, leave them on the tape. When you need matched sets, you can pull off adjacent resistors and be reasonably confident that they will match and track well.

Traditionally, the best, most stable resistors have been wirewound resistors **(Fig 1c)**. These days, film resistors can match wirewound resistors quite well for almost any set of specifications. However, for a resistor whose value is between 200 kΩ and 1 MΩ, wirewound resistors are more expensive and come only in larger packages. Wirewound resistors also have one major disadvantage: the inductance of an ordinary wirewound resistor makes achieving fast (sub-μsec) settling impossible. However, you can specify a special winding pattern that can greatly cut down the inductance of the windings. This type is listed in several manufacturers' catalogs as "Type HS." But I've found that there are two different types of HS: one type has almost zero inductance and greatly increased interwinding capacitance; the other type has low inductance and low capacitance and is well suited for fast-settling amplifiers. Be cautious of manufacturers' oversimplified statements.

***Bob uses carefully selected precision resistors** to model the resistance of the metal runs of a FET op amp.*

A tricky problem popped up a couple of years ago when we assembled a precision amplifier with wirewound resistors. The output was drifting all over the place, but the amplifier, zeners, and transistors were stable. What was drifting? It turned out that a wirewound resistor was "drifting" because we had mistakenly used a special temperature-compensating resistor with a TC of +3300 ppm/°C. This type of temperature-compensating resistor is often used for correcting the TC of transistor logging circuits, but it wasn't labelled in an obvious way. When we put this resistor in a circuit where a low-TC resistor was required, it took us a couple of hours of troubleshooting to pinpoint the problem.

Match the TC to the application

Diffused resistors, commonly used in ICs, have some strange characteristics. Their TC is high—+1600 ppm/°C—and includes a nonlinear, or quadratic, term. Thus,

Resistor problems are often due to using the wrong type of resistor for your application.

the resistance goes up faster at high temperatures than it falls at cold temperatures. These resistors would be useless except for one minor detail: They track at the rate of approximately ±5 ppm/°C. Since it is very inexpensive to make matched pairs or sets of these resistors in a monolithic integrated circuit, their use is popular among IC designers. If you're not designing an IC, though, you probably won't meet up with diffused resistors very often.

Many ICs, such as DACs and voltage references, are made with thin-film (sichrome or nichrome) resistors on the chip. Compared with most other resistor types, these resistors have the somewhat lower TCs of 50 to 350 ppm/°C, closer ratios, better long-term stability, better TC tracking, and less nonlinearity of the "voltage coefficient." This last term refers to the nonlinearities in Ohm's Law that occur when there is a large voltage drop across a resistor; the effect is most common in resistors with large values.

Therefore, when you drive the reference input to a DAC, you should be aware that the R_{in} will only shift 1 to 3% over the entire temperature range. However, there may still be a broad tolerance, as it is not easy to keep tight tolerances on the "sheet rho," or resistivity, during the IC's production. For example, a typical DACs R_{in} specification is 15 kΩ ±33%. These film resistors have even better tracking TC than diffused resistors, often better than 1 ppm/°C.

In addition to the TC, you might also be concerned with the shunt capacitance of a resistor. Recently, I was trying to build a high-impedance probe with low shunt capacitance. I wanted to put a number of 2.5-MΩ resistors in series to make 10 MΩ. I measured the shunt capacitance of several resistors with our lab's impedance bridge. A single Allen-Bradley carbon-composition resistor had a 0.3-pF capacitance, so the effective capacitance of four in series would be down near 0.08 pF—not bad **(Fig 2)**. Then I measured a Beyschlag carbon-film resistor. Its capacitance was slightly lower, 0.26 pF. The capacitance of a Dale RN60D was 0.08 pF; the capacitance of four in series would be almost unmeasurable.

It would be an improper generalization to state that certain resistor types have less shunt capacitance than others. However, the main point is that if you need a resistance with low shunt capacitance, you can connect lower-value resistors in series.

As with the fixed resistors discussed so far, there are many kinds and types of variable resistors, such as trimming potentiometers, potentiometers, and rheo-

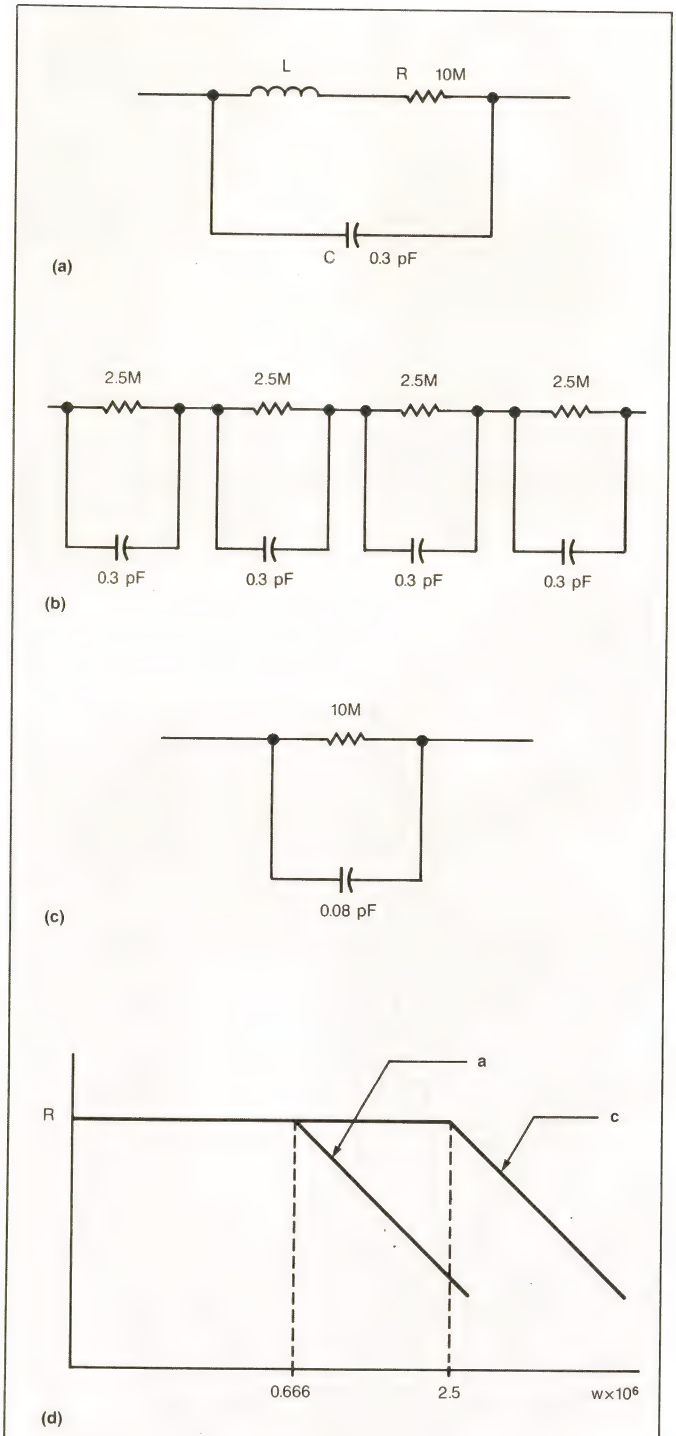

***Fig 2—You can reduce the capacitance** of a single resistor **(a)** by using several resistors in series as shown in **b** (assume the inductance is negligible). This series resistor configuration has one fourth of the single resistor's capacitance **(c)** and extends the resistor's frequency response as shown in **d**.*

stats. These resistors are made with many different resistive elements, such as carbon, cermet, conductive plastic, and wire. As with fixed resistors, be careful of inexpensive carbon resistors, which may have such poor TC that the manufacturer avoids any mention of it on the data sheet. These carbon resistors would have a poor TC when used as a rheostat but might have a good TC when used as a variable voltage divider or a potentiometer. On the other hand, some of the cermet resistors have many excellent characteristics but are not recommended for applications that involve many hundreds of wiper cycles. For example, a cermet resistor would be inappropriate for a volume control on a radio.

The major problem area for variable resistors is their resolution, or "settability." Some variable resistors claim to have infinite resolution; but, if you apply 2V across a variable resistor's ends and try to trim the wiper voltage to any or every millivolt in between, you may find that there are some voltage levels you can't achieve. So much for infinite resolution. As a rule of thumb, a good pot can usually be set to a resolution of 0.1%, or every 2 mV in the previous case. Thus, counting on a settability of 0.2% is conservative.

Good settability includes not only being able to set the wiper to any desired position but also having it stay there. But, I still see people advertising multiturn pots with the claimed advantage of superior settability. The next time you need a pot with superior settability, evaluate a multiturn pot and a single-turn pot. Set each one to the desired value, tap the pots with a pencil, and tell me which one stays put. I normally expect a multiturn pot, whether it has a linear or circular layout, to be a factor of 2 to 4 worse than a single-turn pot because the mechanical layout of a single-turn pot is more stable and balanced. Does anyone know of an example in which the multiturn pot is better?

Don't exceed your pot's I and V ratings

How do variable resistors fail? If you put a constant voltage between the wiper and one end and turn the resistance way down, you will exceed the maximum wiper current rating and soon damage or destroy the wiper contact. Note that the power rating of most variable resistors is based on the assumption that the power dissipation is uniformly distributed over the entire element. If half of the element is required to dissipate the device's rated power, the pot may last for a short while. However, if a quarter of the element is required to dissipate this same amount of power, the pot will fail quickly. For example, many years ago, the only ohmmeters available might put as much as 50 mA into a 1-Ω resistor. When a 50-kΩ, 10-turn precision potentiometer (think of a $20 item) was tested at

Consider the effects of magnetic fields

One problem recently illustrated the foibles of inductor design: Our applications engineers had designed several dc/dc converters to run off 5V and to put out various voltages, such as +15V and −15V dc. One engineer built his converter using the least expensive components, including a 16-cent, 300-μH inductor wound on a ferrite rod. Another engineer built the same basic circuit but used a toroidal inductor that cost almost a dollar. Each engineer did a full evaluation of his converter; both designs worked well.

Then the engineers swapped breadboards with each other. The data on the toroid-equipped converter was quite repeatable. But, they couldn't obtain repeatable measurements on the cheaper version. After several hours of poking and fiddling, the engineers realized that the rod-shaped inductor radiated so much flux into the adjacent area that all measurements of ac voltage and current were affected. With the toroid, the flux was nicely contained inside the core, and there were no problems making measurements. The engineers concluded that they could build the cheapest possible converter, but any nearby circuit would be subject to such large magnetic fields that the converter might be useless.

When I am building a complicated precision test box, I don't even try to build the power supply in the main box because I know that the magnetic fields from the power transformer will preclude low-noise measurements and the heat from the transformer and regulators will degrade the instrument's accuracy. Instead, I build a separate power-supply box on the end of a 3-ft cable; the heat and magnetic flux are properly banished from my precision circuits.

The easiest way to spot problems with resistors and inductors is to follow your nose.

incoming inspection using such an ohmmeter, the tester would turn the pot down to the end where the 50 mA was sufficient to burn out the delicate wirewound element—an inefficient way to test parts.

Some trimming potentiometers are not rated to carry any significant dc current through the wiper. This dc current—even a microampere—could cause electromigration, leading to an open circuit or noisy, unreliable wiper action. Carbon pots are not likely to be degraded by this failure mode. If you have any questions about the suitability of your favorite trimming potentiometers for rheostat service, you or your components engineer should ask the pot's manufacturer.

How do you spot resistor problems? The most obvious way is to follow your nose. When a resistor is dying it gets quite hot, and sometimes the strong smell leads right to the abused component. Just be careful not to burn your fingers.

You may also encounter situations in which a resistor hasn't truly failed but doesn't seem to be doing its job, either. Something seems to be wrong with the circuit, and a resistor of the wrong value is the easiest explanation. So, you measure the resistor in question, and 90% of the time the resistor is just fine—usually the trouble is elsewhere. A resistor doesn't usually fail all by itself. Its failure is often a symptom that a transistor or circuit has failed; if you just replace the resistor, the new one will also burn out or exhibit the same strange characteristics.

How do you check for resistor errors? If you're desperate, you can disconnect one end of the resistor and actually measure its value. It's often easier to just measure the $I \times R$ drops in the network and deduce which resistor, if any, seems to be of the wrong value. If one resistor is suspected of being temperature sensitive, you can heat it with a soldering iron or cool it with freeze mist as you monitor its effect. In some solid-state circuits, the signals are currents, so it's not easy to probe the circuit with a voltmeter. In this case, you may have to make implicit measurements to decide if a resistor is the problem. Also, remember that a sneak path of current can often cause the same effect as a bad resistor.

Watch out for damaged components

Damaged resistors can also be the source of trouble. A resistor that's cracked can be noisy or intermittent. When resistors are overheated with excess power, such as 2 or 3W in a ¼W resistor, they tend to fail "open"—they may crack apart, but they don't go to low ohms or to a short circuit. The accuracy or stability of a high-value resistor (10^8 to $10^{12}\Omega$) can be badly degraded if dirt or fingerprints touch its body. Careful handling and cleaning are important for these high-value resistors and high-impedance circuits.

One problem that occurs with all resistors is related to the Seebeck effect: the production of an EMF in a circuit composed of two dissimilar metals when their two junctions are at different temperatures. In precision circuits, you should avoid thermal gradients that could cause a large temperature difference across a critical resistor. Many precision wirewound and film resistors have low Seebeck coefficients in the range 0.3 to 1.5 μV/°C. But avoid tin oxide resistors, which have a thermocouple effect as large as 100 μV/°C. If you are going to specifiy a resistor for a critical application where thermocouple errors could degrade circuit performance, check with the manufacturer.

So, know that resistors can present challenging troubleshooting problems. Rather than reinventing the wheel every time, try to learn from people with experience.

Inductors and transformers aren't so simple

Inductors and transformers are more complicated than resistors—nonlinearity is rife. Their cores come in many different shapes and sizes, from toroids to pot cores and from rods to stacks of laminations. Core materials range from air to iron to any of the ferrites. I am not going to presume to tell you how to design an inductor or transformer or how to design circuits that use them, but I will discuss the kinds of trouble you can have with these components. For example, you can have a good core material; but, if there is an air gap in the core and you don't carefully control the gap's width, the energy storage and the inductance of the component can vary wildly. If someone has substituted a core of the wrong material, you may have trouble spotting the change; an inductance meter or an impedance bridge can help. But even with one of those tools, you're not home free.

For most inductors and transformers with cores composed of ferromagnetic materials, you had better make sure that the test conditions—the ac voltage and the frequency that the measuring instrument applies to the device under test—closely approximate those the component will see in your real-life application. If you fail to take such precautions, your inductance measurements stand a good chance of seriously misleading you and making your troubleshooting task much more frus-

trating. The phenomena you are likely to run into as a result of incorrect test conditions include saturation, which can make the inductance look too low, and core loss, which can lower the Q of an inductor. For transformers, make sure you understand which of the inductances in the device's equivalent circuit you are measuring. (For more on transformer equivalent circuits see **box,** "Equivalent circuits demystify transformers.")

When you work with inductors or transformers, you have to think in terms of current: In any transformer or inductor, flux is directly proportional to the current, and resistive losses are directly proportional to the current squared. Therefore, be sure to have several current probes, so you can observe what the current waveforms are doing. After all, some of the weirdest, ugliest, and most nonideal waveforms you'll see are the waveforms associated with inductors.

In the absence of an instrument designed to measure inductance, parallel the inductor with a known capacitance to create a parallel resonant circuit. If you use a high-impedance source to apply a current pulse to this circuit, you can determine the inductor's value from the resonant frequency and the capacitance: $f=1/2\pi\cdot\sqrt{LC}$. If you look at the inductor's waveform on a scope, you can compare it to the waveform you get with a known-good inductor. This technique is also good for spotting a shorted turn, which reduces inductance nearly to zero. The L meter and the similar Q meter can help you ensure that good inductors haven't been

Equivalent circuits demystify transformers

You can represent a transformer with a turns ratio of N as a "T" network **(Fig A).** N equals N_1/N_2, where N_2 is the number of secondary turns and N_1 is the number of primary turns. However, if you plan to make measurements on transformers, it's helpful to keep the equivalent circuit shown in **Fig B** in mind. For example, the inductance you measure between terminals A and B is quite large if you leave terminals C and D open, but the measured inductance is quite small if you short terminals C and D together.

In the first case, you are measuring the mutual inductance plus the leakage inductance of the primary. But because the leakage inductance is normally much, much smaller than the mutual inductance, you are measuring the leakage inductance of the primary plus the reflected secondary leakage in the second case.

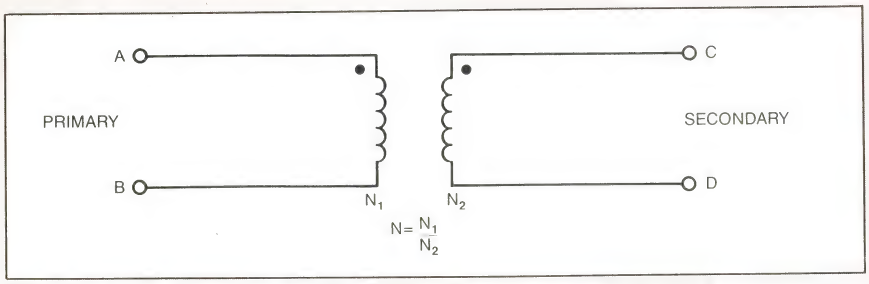

Fig A—In most instances, *you can represent a transformer by its turns ratio.*

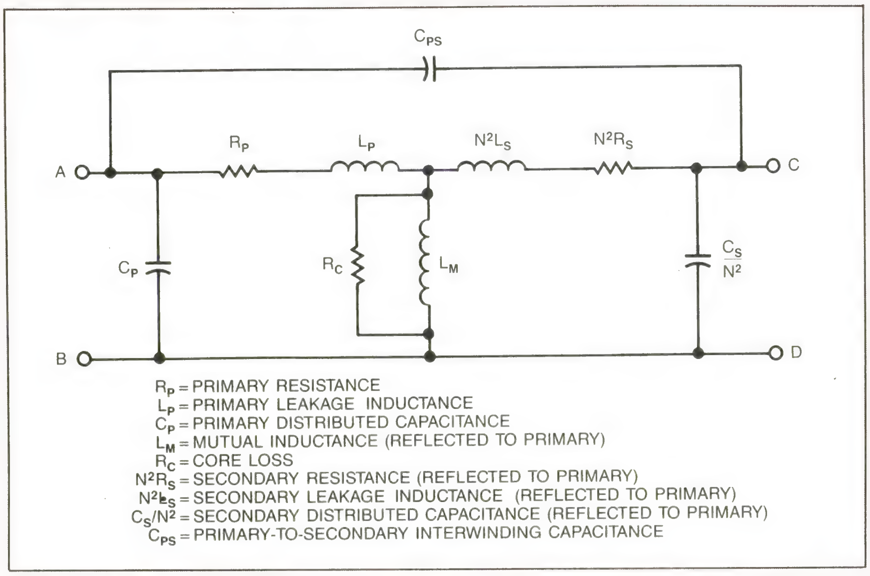

Fig B—If you are measuring the characteristics of transformers, *you should keep its equivalent circuit in mind. Considering the effect of each component will help you understand the results of your measurements.*

When working with inductors or transformers, think in terms of current and use current probes to view the waveforms.

damaged by saturation.

Incredible as it may sound, you can permanently damage an inductor by saturating it. Some ferrite toroids achieve their particular magnetic properties by dint of operation at a particular point on the material's magnetization curve. Saturating the core can move the operating point and drastically change the core's magnetic properties. The likelihood of your being able to return the material to its original operating point is small to nonexistent. In other cases, as a result of applying excessive current, the core temperature increases to a point where the core's magnetic properties change irreversibly. Regardless of the mechanism that caused the damage, you may have to do as I once did—package the inductors with a strongly worded tag to demand that nobody test them at Incoming Inspection.

If you choose too small a wire size for your windings, the wire losses will be excessive. You can measure the winding resistance with an ohmmeter, or you can measure the wire's thickness. But if the number of turns is wrong, you can best spot the error with an L meter—remember that $L \propto N^2$. Be careful when using an ohmmeter to make measurements on transformers and inductors—some ohmmeters put out so many milliamps that they are likely to saturate the component you are trying to measure and at least temporarily alter its characteristics.

Protect transistors from voltage kick

There is one trouble you can have with an inductor that will not do any harm to the magnetic device but will leave a trail of death and destruction among its associated components: When you use a transistor to draw a lot of current through an inductor and then turn the transistor off, the "kick" from the inductor can generate a voltage high enough to destroy almost any transistor. You can avoid this problem by connecting a suitable snubber, such as a diode, an RC network, a zener, or a combination of these components, across the inductor to soak up the energy. The use of a snubber is an obvious precaution, yet every year I see a relay driver with no clamp to protect the transistor. The transistor may survive for a while, but not for long.

The tiniest inductors are called beads. They are about the same size and shape as beads worn as jewelry and have room for only one or two or four turns of wire. Beads are commonly used in the base or emitter of a fast transistor to help keep it from oscillating. A bead not only acts inductive but also acts lossy at high frequencies, thus damping out ringing. In general, the choice of a bead is an empirical, seat-of-the-pants decision, but designers who have a lot of experience in this area make good guesses. This topic is one that I have not seen treated, except perhaps one sentence at a time, in any book or magazine. You'll just have to get a box of ferrite beads and experiment.

Transformers usually are susceptible to the same problems as inductors. In addition, the turns ratio may be wrong, or the winding polarity might be incorrect. And, if your wire-handling skills are sloppy, you might have poor isolation from one winding to another. Most ferrite materials are insulators, but some are conductive. So, if you've designed a toroidal transformer whose primary and secondary windings are on opposite sides of the toroid and you scrape off the core's insulating coating, you could lose your primary-secondary insulation. If the insulating coating isn't good enough, you might want to put tape over the toroid.

Fortunately, it's easy to establish comparisons between a known-good transformer and a questionable one. If you apply the same input to the primaries of both transformers, you can easily tell if the secondaries are matched, wound incorrectly, or connected backwards. If you're nervous about applying full line voltage to measure the voltages on a transformer, don't worry—you can drive the primary with a few volts of signal from a function generator and still see what the various windings are doing.

Two general problems can afflict power transformers. The first occurs when you have large filter capacitors and a big high-efficiency power transformer. When you turn the line power switch on, the inrush current occasionally blows the fuse. You might install a larger value of fuse, but then you must check to make sure that the fuse is not too high to offer protection. As an alternative, you could specify the transformer to have a little more impedance in the secondary: Use smaller wire for the windings or put a small resistor in series with the secondary.

Another approach, often used in TV sets, is to install a small negative-TC thermistor in the line power's path. The thermistor starts out with a nominal impedance, so the surge currents are finite. But then the thermistor quickly heats up, and its resistance drops to a negligible value. Thus, the efficiency of the circuit is quite good after a brief interval. If the circuit is a switch-mode power supply, the control IC should start up in a "soft-start" mode. In this mode, the IC won't draw any extreme currents in an attempt to charge

In the absence of an instrument designed to measure inductance, parallel the inductor with a known capacitance to create a parallel resonant circuit.

up the output capacitors too quickly. However, you must use caution when you apply thermistors for inrush current limiting: Beware of removing the input power and then reapplying it before the thermistors have had a chance to cool. A warm thermistor has low resistance and will fail to limit the current; thus, you are again likely to blow a fuse.

The second general problem with a line transformer occurs when you have a small output filter capacitor. In our old LM317 and LM350 data sheets, we used to show typical applications for battery chargers with just a 10-μF filter. Our premise was that when the transformer's secondary voltage dropped every 8 msec, there was no harm in letting the regulator saturate. That premise was correct, but we began to see occasional failed regulators that blew up when we turned the power on.

After extensive investigations, we found the problem in the transformer: If the line power switch was turned off at exactly the wrong time of the cycle, the flux in the transformer's steel core could be stored at a high level. Then, if the line power switch was reconnected at exactly the wrong time in the cycle, the flux in the transformer would continue to build up until the transfomer saturated and produced a voltage spike of 70 to 90V on its secondary. This spike was enough to damage and destroy the regulator. The solution was to install a filter capacitor of at least 1000 μF, instead of just 10 μF. This change cut the failure rate from about 0.25% to near zero.

Another problem occurred when the LM317 was used as a battery charger. When the charger output was shorted to ground, the LM317 started drawing a lot of current. But, the transformer's inductance kept supplying more and more current until the LM317 went into current limit and could not draw any more current. At this point, the transformer's secondary voltage popped up to a very high voltage and destroyed the LM317. The addition of the 1000-μF snubber also solved this problem.

Inductors, like resistors, can overheat

How do you spot a bad inductor or transformer? I have already discussed several mechanisms that can cause the inductance or Q of an inductor to be inferior to that of a normal part. And, as with a resistor, you can smell an inductor that is severely overheating. Overheating can be caused by a faulty core, a shorted turn, incorrect wire gauge, or anything else that causes losses to increase. An open winding is easy to spot with an ohmmeter, as is a short from a primary to a secondary. If the pattern of winding has been changed from one transformer to another, you may not see it unless you test the components in a circuit that approximates the actual application. However, you may also be able to see such a discrepancy if you apply a fast pulse to the two transformers.

Tightly coupled windings, both bifilar and twisted pairs, have much better magnetic coupling and less leakage inductance than do well-separated primary and secondary windings. As the magnetic coupling improves, the capacitance between windings increases—but high capacitance between windings is often an undesirable effect in a transformer. An experienced transformer designer weighs all the tradeoffs and knows many design tricks—for example, the use of special pi windings and Litz wire. Mostly, you should know that these special techniques are powerful; if you ask the transformer designers the right questions, they can do amazing tricks.

I recently read about an engineer who designed an elegant shield made of mu-metal. However, the shield was difficult to install, so the technician had to tap on it with a hammer. When the engineer operated the circuit, the shielding seemed nonexistent—as if the shield were made of cardboard. After a lot of studying, the engineer realized that the mu-metal—which costs about $2 per 15 square inches, the same as a $2 bill—had been turned into perfectly worthless material by the pounding and hammering. In retrospect, the engineer had to admit that the mu-metal, when purchased, was prominently labelled with a caution against folding, bending, or hammering. So remember, in any area of electronics, there are problems with inductors and magnetic materials that can give you gray hair. EDN

Author's biography

For information about Bob Pease, see the box, "Who is Bob Pease, anyway?" in the January 5, 1988, edition of EDN.

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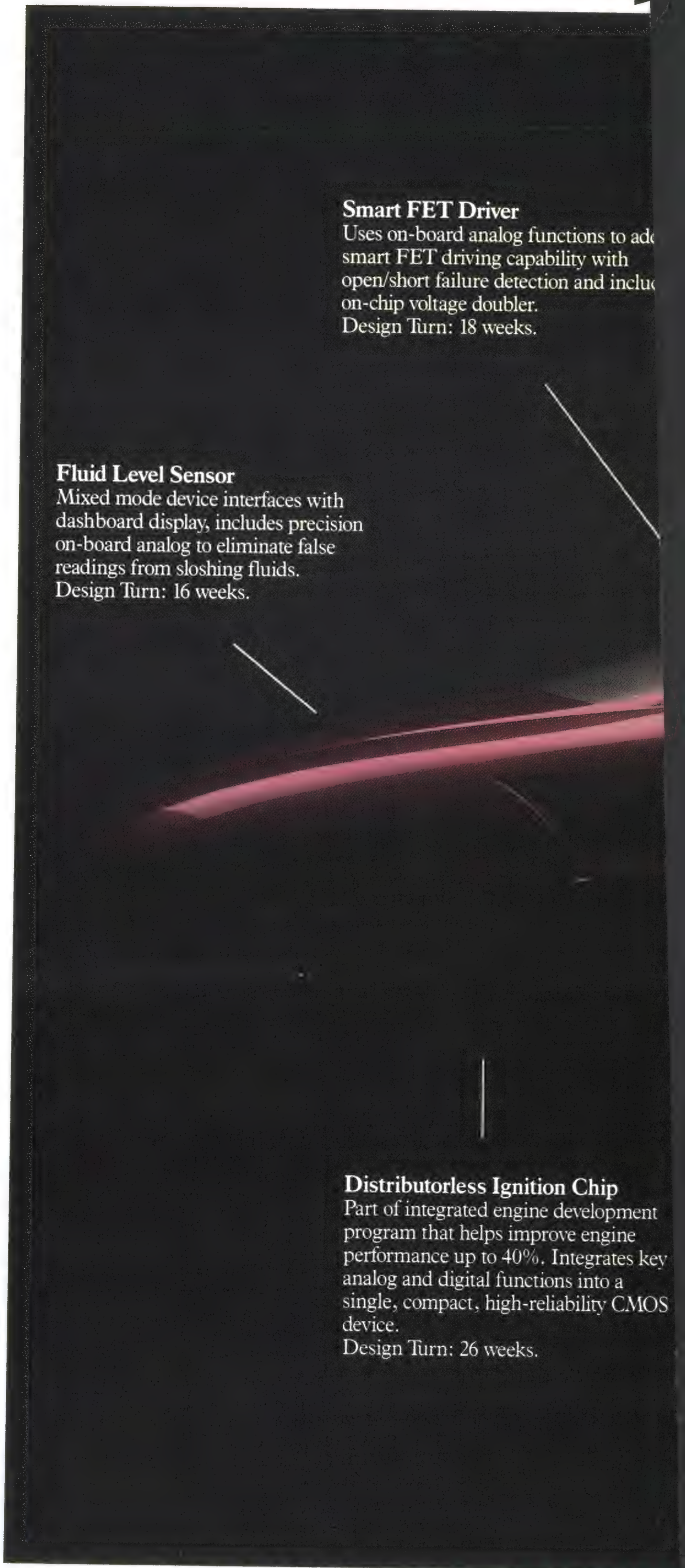

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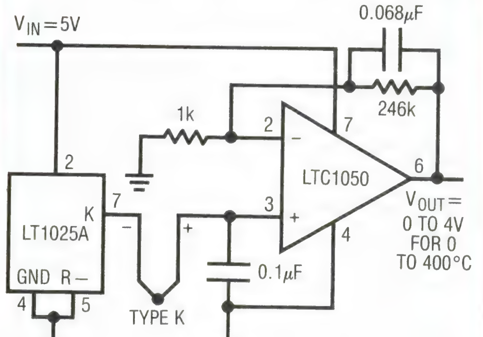

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CIRCLE NO 59

PLD monitors multiple inputs

Christoph Kontek
Institutue for Nuclear Studies, Swierk, Poland

The equations in **Listing 1** will program a 20L8 PLD to recognize if one or more than one of its inputs is asserted at a time. The PLD checks whether the number of active inputs equals zero (output ZERO), one (outputs ONE0, ONE1, ONE2), more than one (output MORE), or at least one (PRES).

This design has several advantages over ideas presented earlier (see "Tree structure detects multiple inputs," *EDN*, Feb 19, 1987, and "Adders enable detection of multiple inputs," *EDN*, April 28, 1988): It requires fewer ICs, its response time does not depend on the order of active inputs, and you can enlarge the design by either cascading 24-pin PLDs or by using a larger PLD, such as an Altera EP1800.

Further, you could take advantage of other PLDs to tailor this design for your own application. You could, for example, have active-high outputs. Or, you could use a device that has registers to build a faster, pipelined unit. EDN

To Vote For This Design, Circle No 749

LISTING 1—MULTIPLE-INPUT DETECTOR PLD

```
CHIP Detector                PAL20L8

;PINS 1   2   3   4   5   6   7   8   9    10   11   12
      D2  D3  D4  D5  D6  D7  D8  D9  D10  D11  D12  GND

;PINS 13  14   15    16   17    18    19    20    21  22    23  24
      D13 D14 /PRES  D15 /ZERO /ONE0 /ONE1 /ONE2  D0 /MORE  D1  VCC

EQUATIONS

ZERO = D15*D14*D13*D12*D11*D10*D9*D8*D7*D6*D5*D4*D3*D2*D1*D0

ONE0 = D15*D14*D13*D12*D11*D10*D9*D8*D7*D6*D5*D4*D3*D2*D1*/D0
     + D15*D14*D13*D12*D11*D10*D9*D8*D7*D6*D5*D4*D3*D2*/D1*D0
     + D15*D14*D13*D12*D11*D10*D9*D8*D7*D6*D5*D4*D3*/D2*D1*D0
     + D15*D14*D13*D12*D11*D10*D9*D8*D7*D6*D5*D4*/D3*D2*D1*D0
     + D15*D14*D13*D12*D11*D10*D9*D8*D7*D6*D5*/D4*D3*D2*D1*D0
     + D15*D14*D13*D12*D11*D10*D9*D8*D7*D6*/D5*D4*D3*D2*D1*D0

ONE1 = D15*D14*D13*D12*D11*D10*D9*D8*D7*/D6*D5*D4*D3*D2*D1*D0
     + D15*D14*D13*D12*D11*D10*D9*D8*/D7*D6*D5*D4*D3*D2*D1*D0
     + D15*D14*D13*D12*D11*D10*D9*/D8*D7*D6*D5*D4*D3*D2*D1*D0
     + D15*D14*D13*D12*D11*D10*/D9*D8*D7*D6*D5*D4*D3*D2*D1*D0
     + D15*D14*D13*D12*D11*/D10*D9*D8*D7*D6*D5*D4*D3*D2*D1*D0

ONE2 = D15*D14*D13*D12*/D11*D10*D9*D8*D7*D6*D5*D4*D3*D2*D1*D0
     + D15*D14*D13*/D12*D11*D10*D9*D8*D7*D6*D5*D4*D3*D2*D1*D0
     + D15*D14*/D13*D12*D11*D10*D9*D8*D7*D6*D5*D4*D3*D2*D1*D0
     + D15*/D14*D13*D12*D11*D10*D9*D8*D7*D6*D5*D4*D3*D2*D1*D0
     + /D15*D14*D13*D12*D11*D10*D9*D8*D7*D6*D5*D4*D3*D2*D1*D0

MORE = /ZERO*/ONE0*/ONE1*/ONE2

PRES = /ZERO
```

Converter tracks step functions

Steven Harris
Crystal Semiconductor, Austin, TX

Jamming a CS5012, a CS5014, or a CS5016 A/D converter into its coarse-charge mode allows it to track and convert signals containing step functions. The devices' on-chip track-and-hold function normally spends six clock cycles in coarse-charge mode immediately after finishing a conversion. You must then allow a minimum of nine clock cycles of fine-charge mode before bringing HOLD low to freeze the sample and initiate a conversion. If, however, a step-change input occurs after the A/D converter is in fine-charge mode, the track-and-hold circuit will not be able to follow the step.

Fig 1 shows a circuit that jams an A/D converter into coarse charge mode, instead of fine-charge mode, by stopping the converter's clock at a high state at the end of each conversion. The end-of-convert (EOC) signal clocks the D flip-flop's Q output to zero, thereby jamming CLKIN high via a NAND gate. An RST signal unjams the A/D converter at least 15 clock cycles before HOLD goes low to capture the signal. This technique proves particularly useful when you use the converter to digitize the output of a CCD or PIN diode array where the analog data has "black" reference levels between valid light-intensity levels. EDN

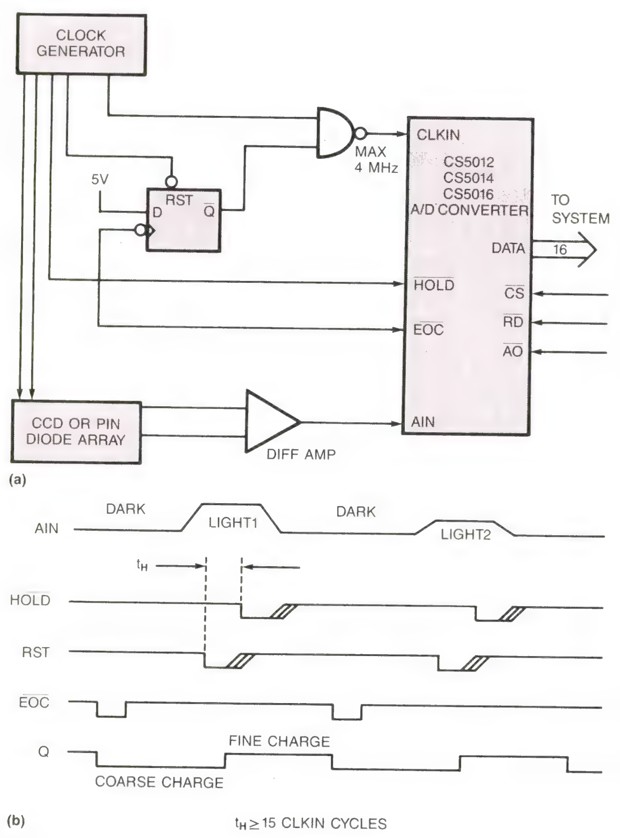

Fig 1—This circuit jams an A/D converter into its coarse-charge mode, so that the converter can better track step changes at its input.

To Vote For This Design, Circle No 748

Hardware increases interrupt lines

Fabio Ricci
OTE Biomedica, Firenze, Italy

Because 8-bit μPs often have only one interrupt line, you must do extensive testing in software to service multiple interrupt sources. In the circuit in **Fig 1,** external hardware has been added to a 6809 μP that allows the μP to respond to one of eight interrupts immediately without performing any software tests. This circuit can handle eight interrupts because the external hardware supplies a different hardware-interrupt vector for each interrupt source. Normally, the 6089 can fetch only the starting address of a single interrupt-handling routine in response to an interrupt request.

When the circuit senses one or more external interrupts, it signals the μP by asserting pin 14 (GS) of priority encoder IC_4. In response, the μP begins a

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Max, 20dB Stop Frequency (MHz)	19	32	47	70	90	147	210	290	410	580	750	840	1000	1100	1340

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HIGH PASS Model *HP-		50	100	150	200	250	300	400	500	600	700	800	900	1000
Pass Band (MHz)	start, max.	41	90	133	185	225	290	395	500	600	700	780	910	1000
	end, min.	200	400	600	800	1200	1200	1600	1600	1600	1800	2000	2100	2200
Min. 20dB Stop Frequency (MHz)		26	55	95	116	150	190	290	365	460	520	570	660	720

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*Prefix P for pins, B for BNC, N for Type N, S for SMA   example: PLP-10.7

C105 REV. E

CIRCLE NO 58

normal interrupt-response sequence. The circuit monitors the BS and BA status lines from the μP because the μP asserts BA=0 and BS=1 when fetching the interrupt vector from memory locations $FFF8_{HEX}$ and $FFF9_{HEX}$. Upon detecting such a fetch, the IRQ-detection portion of the circuit asserts pin 12 of IC_6, which switches the state of multiplexer IC_5.

This line is normally low to allow normal connection between EPROM IC_7's address inputs and the address bus. When the multiplexer changes state, it switches this EPROM's $A_{1\text{-}4}$ inputs from the address bus to the output of priority encoder IC_4. The inputs to the priority encoder are the eight interrupts and its output is a 3-bit value corresponding to the highest-priority asserted interrupt.

Thus, instead of fetching the starting address of a single interrupt routine, the μP acquires one of eight different starting addresses corresponding to the highest-priority interrupt asserted. Register IC_1 holds an interrupt mask with which you can selectively disable any of the interrupts.

Only the interrupt-sequence-detection portion of this circuit is peculiar to the 6809. You can easily adapt the rest of the circuit to any μP.

To Vote For This Design, Circle No 747

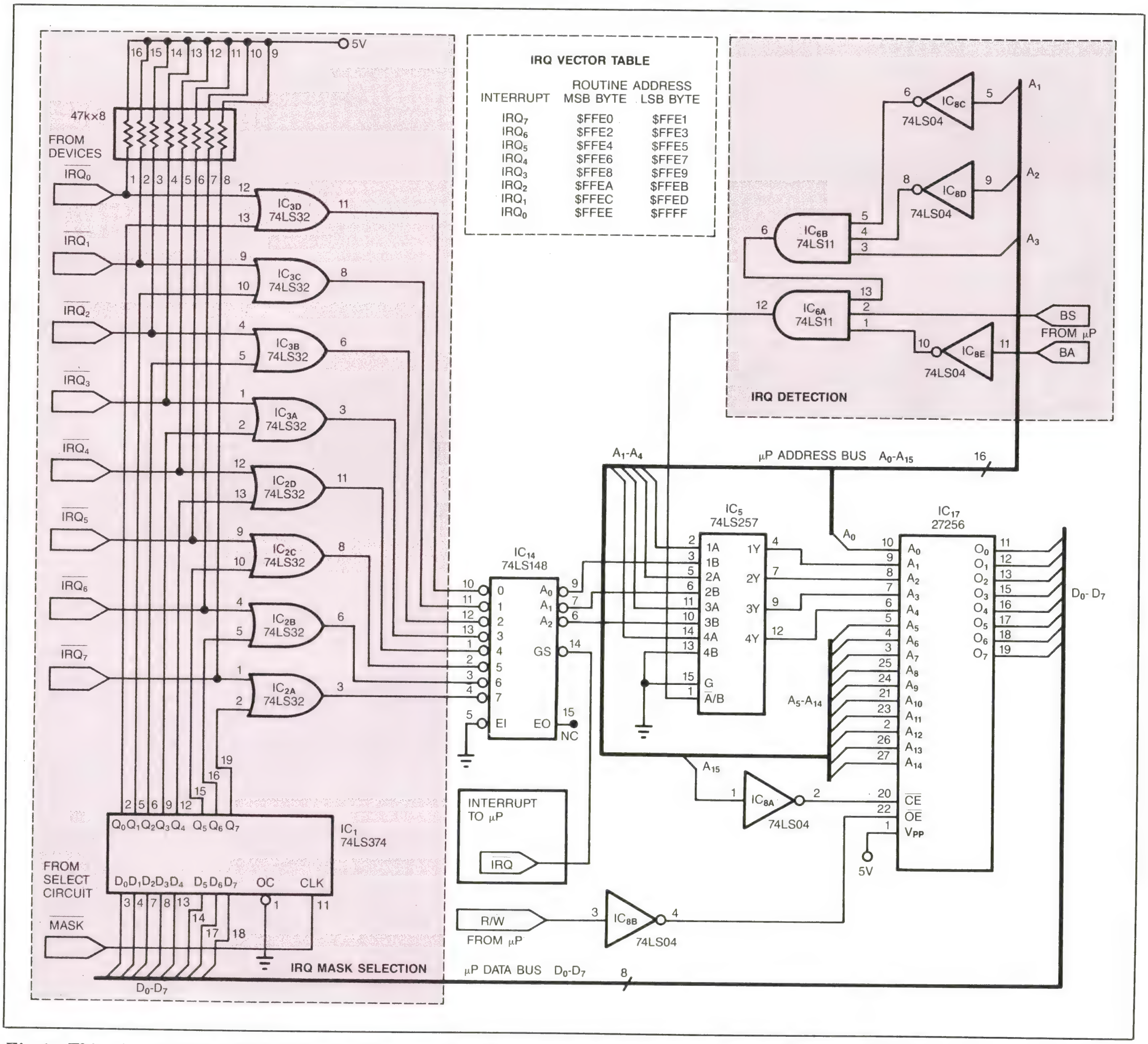

Fig 1—This circuit fools a 6809 into acquiring one of eight different interrupt-vector-routine starting addresses instead of just a single vector by disconnecting three of the μP's EPROM's address lines from the address bus momentarily and connecting them, instead, to the interrupt lines via a priority encoder.

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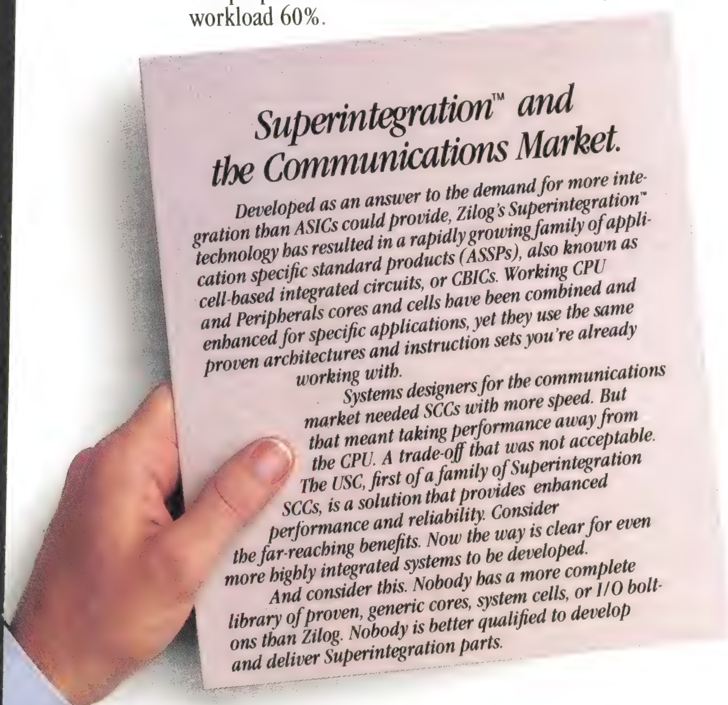

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CIRCLE NO 57

Algorithm tests for set bit

Alfred E Knecht
Sysoft SA, Montagnola, Switzerland

The simple programs in **Listing 1** are Z80 assembly-language and Turbo Pascal versions of an algorithm that tests a variable to see if it contains at most one set bit. You might have to perform this test, for example, to determine whether a variable is a power of two or whether at most one bit from an input port is set.

Conventional methods for this test might entail a sequence of explicit compares, a loop that successively shifts and compares the carry bit, or a lookup table that uses the variable's value as an index.

By contrast, the algorithm used in the **listing** is stunningly simple: It first decrements the variable and then ANDs the original value with the decremented value—a zero result means that only one bit was set.

To understand how the algorithm works, consider that if you decrement by one a bit string containing a single set bit, the following happens: The set bit becomes a zero, all bits to the right of the original set bit change from zero to one, and all bits to the left of the original set bit are unchanged as zero. If, instead, you decrement a bit string containing more than one set bit, the leftmost one remains a one; some bits, but not all, to the right of the leftmost bit change state; and bits to the left of the leftmost one remain zero.

In the case of the bit string having only one bit set, ANDing the original value with the decremented value will produce an all-zero result. However, in the case of the bit string having more than one bit set, the AND operation will have a nonzero result.

If the range of values you are testing can include all zeros, you must test for this condition before performing the algorithm.

To Vote For This Design, Circle No 750

LISTING 1—SINGLE-BIT-SET TESTS

```
ATMOSTONE:      ;this routine answers the question
                ; "is there at most one bit set in the argument".
                ; Argument is a byte, in register C.
                ; Result: true ==> zero flag set
                ;         false ==> zero flag reset
                LD   A,C  ; get argument into accumulator
                DEC  A    ; decrement it
                AND  C    ; perform AND operation
                RET       ; return result in zero flag
```

```
Function atmostone (x:integer): boolean;
     { return true if x has at most one "1"-bit }
begin
     atmostone:= (x and (x-1)) = 0
end;
```

ISSUE WINNER

The winning Design Idea for the October 27, 1988, issue is entitled "Pseudorandom sequencer simulates flicker," submitted by Andrew K Dart of Andy's Bureau of Standards (Duncanville, TX).

Your vote determines this issue's winner. All designs published win $100 cash. All issue winners receive an additional $100 and become eligible for the annual $1500 Grand Prize. **Vote now**, by circling the appropriate number on the reader inquiry card.

CMOS circuit always oscillates

W F McClelland
Electronic Resources, Stamford, CT

The common clock oscillator in **Fig 1a** has two small problems: It may not, in fact, oscillate if the transition regions of its two gates differ; and, if it does oscillate, it may sometimes oscillate at a slightly lower frequency than its equation predicts because of the finite gain of the first gate. If the circuit does work, oscillation occurs usually because both gates are in the same package and, therefore, have logic thresholds only a few millivolts apart.

The circuit in **Fig 1b** resolves both problems by adding a resistor and a capacitor. The R_2-C_2 network provides hysteresis, thus delaying the onset of Gate 1's transition until C_1 has enough voltage to move Gate 1 securely through its transition region. When Gate 1 is finally in its transition region, C_2 provides positive feedback, thus rapidly moving Gate 1 out of its transition region.

The equations for the oscillator in **Fig 1b** are

$$R_2 = 10R_1$$
$$R_3 = 10R_2$$
$$C_1 = 100C_2$$
$$f \cong \frac{1}{1.2R_1C_1}$$

EDN

To Vote For This Design, Circle No 746

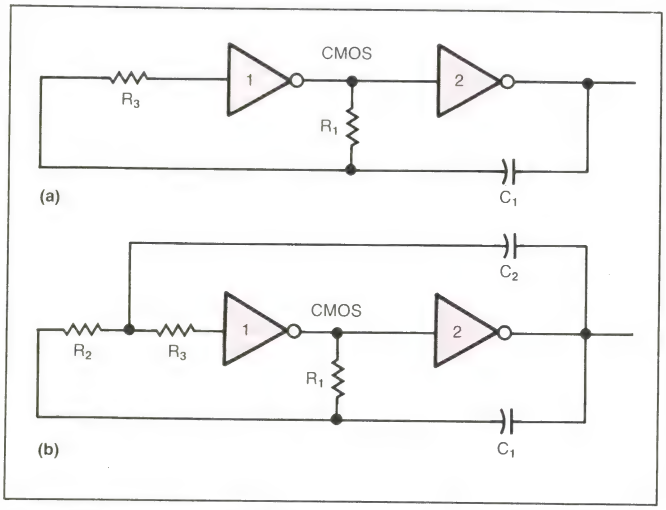

*Fig 1—The conventional CMOS oscillator in **a** sometimes does not oscillate. Or, if it does oscillate, it can oscillate at a lower frequency than you have calculated. The circuit in **b** adds hysteresis to overcome these problems.*

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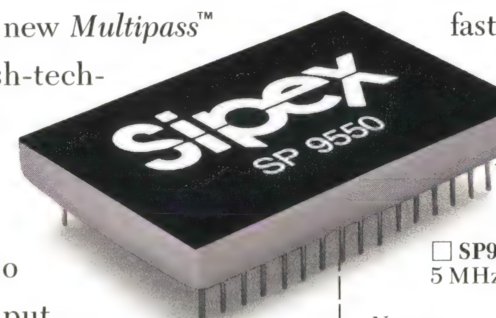

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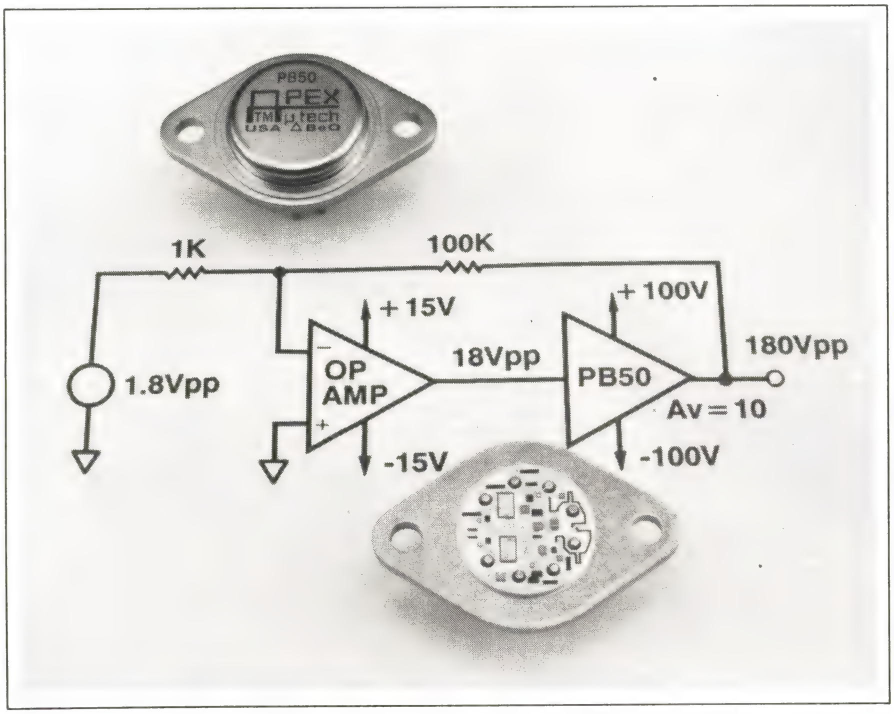

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Circle No 385

CROSSPOINT SWITCH

- *Operates at 50 MHz with signal skew <2 nsec*
- *Has a 32×32 switch matrix*

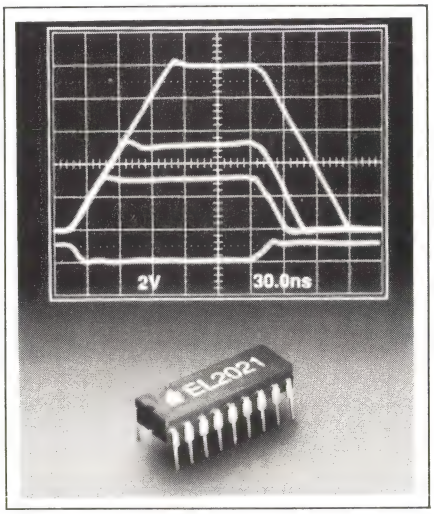
The SC11320 monolithic CMOS 32×32 digital crosspoint switch can independently connect each of its 32 inputs to one or more of its 32 outputs. It produces this matrix switching by using 32 1-of-32 multiplexers—one for each output. A 6-bit latch for each multiplexer permits you to individually load an input address for each output channel. You can create larger matrices by cascading multiple SC11320 switches with the outputs in a wire-ORed, parallel configuration. Further, the outputs have a bit-selectable 3-state mode for those applications where multiple devices must share the same system bus. The SC11320 is available in five package options. Standard 120-pin plastic pin-grid-array version, $81.57 (100).

Sierra Semiconductor, 2075 N Capitol Ave, San Jose, CA 95132. Phone (408) 263-9300. TLX 384467.

Circle No 386

PIN DRIVER

- *Drives analog, ECL, TTL, CMOS, and 10V HCMOS inputs*
- *Logic flag output indicates overcurrent conditions*



The EL2021 monolithic pin driver is suitable for loaded board testing as well as linear or logic bench-top testers. The device can overpower logic outputs and accurately drive independently set high and low levels that have programmed slew rates. The vendor provides dc output levels within 50 mV at a 100-mA load and within 300 mV at a 400-mA load. The EL2021 also has a 3-state capability, allowing you to put the outputs into a high-impedance state for load monitoring. The slew rate is 100V/μsec ±20% with a slew-rate control input of 1V and typically offers a 300V/μsec slew rate at higher control levels. To conserve energy, you can shut down

the EL2021 when it's not in use. Typical quiescent power falls from 625 to 15 mW when you operate the device with supplies at +15V and −10V. EL2021CJ in an 18-pin ceramic DIP, $35 (100).

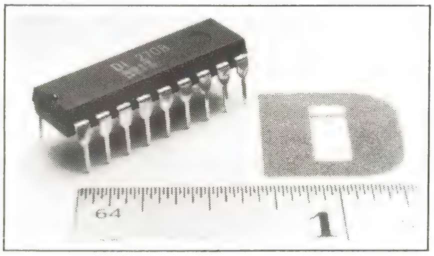
Elantec Inc, 1996 Tarob Ct, Milpitas, CA 95035. Phone (408) 945-1323.

Circle No 387

DECODER/DRIVER

- *Drop-in replacement for DM-8884A*
- *Exhibits low leakage currents at high voltages*

The DI-8884A/DI-270B high-voltage device decodes four lines of BCD input and drives 7-segment digits of gas-filled readout displays. A dielectrically isolated fabrication process increases the high-voltage decoder/driver IC's usable operating voltage from 80 to 110V. In addition, the dielectric isolation ac-



counts for the 8884A's immunity to momentary short-circuit conditions, which occur in gas discharge displays. All outputs consist of switchable and programmable current sinks, which provide constant current to the tube cathodes, even with high-tube anode supply tolerance. You can vary output currents over the 0.2- to 1.2-mA range for multiplex operation; you adjust the output current by connecting an external program resistor from V_{CC} to the program input. $3.15 (1000).

Dionics Inc, 65 Rushmore St, Westbury NY 11590. Phone (516) 997-7474.

Circle No 388

ARCNET CHIP

- *Increases performance by reducing wait states*
- *Quadruples external memory access*

The NCR90C98 1.5-μm CMOS, single-chip implementation of the vendor's NCR90C26 and NCR90C32 offers high performance as a result of additional buffer chaining and reduced wait states. The additional buffer chaining increases throughput by permitting more data packets to pass without intermediate handshaking. The NCR90C98 controls as much as 8k bytes of external RAM. The device features three reset operations: power-on reset, external reset, and software-generated reset. A 20-MHz onboard oscillator simplifies the board design. The NCR90C98 supports all standard ArcNet features, including standardized transfer intervals, as many as 255 nodes, a 2.5M-bit/sec data-transfer rate, the ability to

broadcast messages to all LAN nodes, system protection in the event of a single-node failure, and automatic reconfiguration when the number of nodes changes. It's available in a 40-pin DIP or a 44-pin PLCC. $23 (5000).

NCR Corp, Communications Products Marketing, Dayton, OH 45479. Phone (303) 226-9500.

Circle No 389

COPROCESSOR

- *Works with 80C186 16-bit μP*
- *Accelerates floating-point performance*

Fabricated in the company's CMOS-III process, the 80C187 is a high-performance numeric coprocessor designed exclusively for use with the 80C186 embedded processor. The 80C187 accelerates floating-point operations in numeric-intensive embedded applications. According to the company, the 80C187 offers three times the performance of the 8087 and consumes 75% less power. The 80C187 is object-code compatible with the 8087, allowing OEM's to easily upgrade existing designs. Architectural enhancements allow the 80C187 to perform transcendental functions, such as sine and cosine, in hardware. The 80C187 is available in 12½- and 16-MHz speed ratings and comes in 40-pin ceramic DIPs and 44-pin PLCC packages. $125 and $155 (1000).

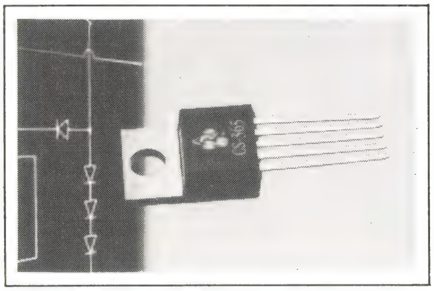
Intel Corp, Box 58065, Santa Clara, CA 95052. Phone (408) 765-4512.

Circle No 390

POWER OP AMP

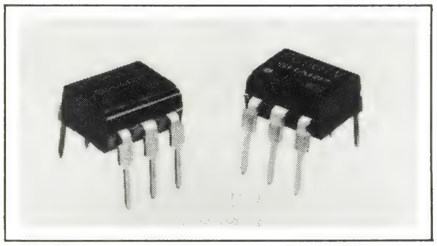
- *Provides 3A output current*
- *Includes on-chip protection*

Operating from a ±6 to ±18V supply, the CS-365 power op amp has an open-loop gain of 80 dB typ, a slew rate of 8V/μsec typ, and an output-current rating of 3A max. Other specs include a typical input noise of 2 μV from 10 Hz to 10 kHz and common-mode rejection of 70 dB. The CS-365 includes on-chip thermal-shutdown and safe-operating-area protection. In addition to its use in motor-control and power-supply applications, the CS-365 can deliver 18W into a 4Ω load when used as an audio amplifier. The op amp comes in a 5-lead TO-220 package. $1.44 (1000).



Cherry Semiconductor Corp, 2000 S County Trail, E Greenwich, RI 02818. Phone (401) 885-3600.

Circle No 391



OPTIC PHOTOCOUPLERS

- *Feature built-in amplifiers*
- *Interface to digital TTL/CMOS*

The PC900V/901V Series optical IC (OPIC) photocouplers incorporate integrated detect and peripheral circuitry elements. The built-in amplifier offers digital switching and high sensitivity. The OPICs produce an input/output isolation voltage of 5 kV rms. Both the PC900V and the PC901V are 6-pin devices, which you can procure in either DIP or gull-wing surface-mount configurations. Since these devices utilize a 1-way signal transmission, output noise has little effect on the input side, making it possible to remove ground-loop and noise-reduction resistors in the transmission line. Further, both OPICs are virtually unaffected by induction or common-mode noise. Bandwidth for the devices ranges from dc to 1 MHz. PC900V, \$0.78; PC901V, \$115 (100).

Sharp Electronics Corp, Sharp Plaza, Mahwah, NJ 07430. Phone (201) 599-8757. FAX 201-529-8759.

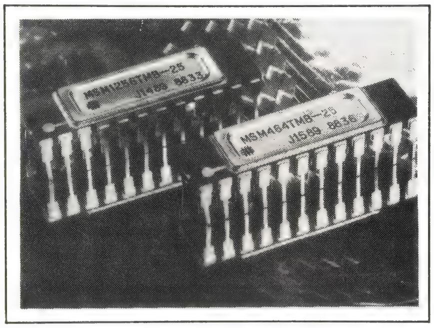
Circle No 392

STATIC RAMs

- *Have an access time as low as 25 nsec*
- *Are available screened to MIL-STD-883C requirements*

The MSM1256 and MSM464 military-grade 256k-bit static RAMs have access times of 25, 35, or 45 nsec and are organized as 256k × 1-bit and 64k × 4-bit configurations, respectively. They are available in 24-pin 0.3-in.-wide DIPs, 24-pin vertical-in-line packages, or 28-pin ceramic LCCs. You can also obtain them screened to MIL-STD-883C requirements. Low-power versions have an active power consumption of 125 mW typ, and a 10-μW standby power consumption. All the RAMs have a bidirectional data port, TTL-compatible inputs and outputs, and a cycle time that's equal to their access time. High-reliability ceramic DIP, £100 (100).

Hybrid Memory Products Ltd, Elm Rd, W Chirton Industrial Es-



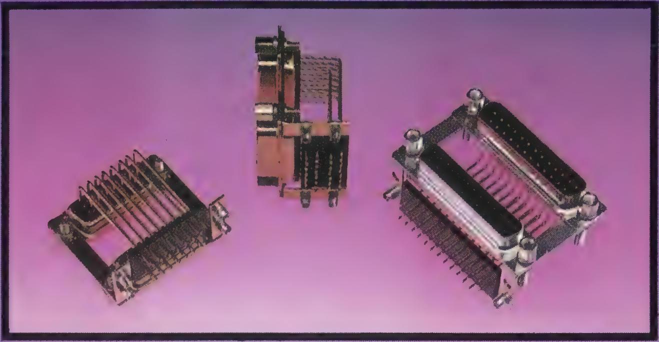
CIRCLE NO 50

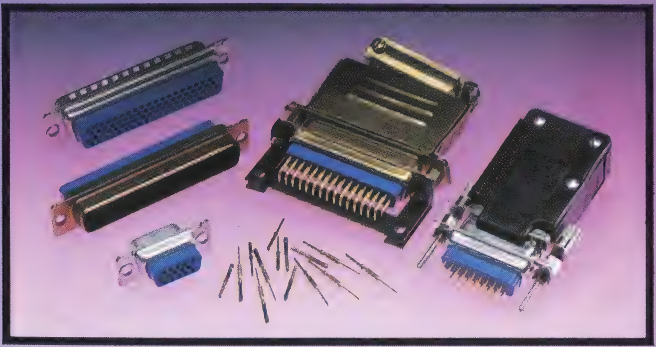
Connector Excellence

DUAL-PORT

Space Saver/Cost Saver Sub-D Connectors

DUAL-PORT VARIANTS: 9, 15, 25, 29, 37 and 50 poles, male or female. **FULLY OR PARTIALLY POPULATED CONNECTORS:** Contacts selectively positioned to order. RS 232, RS 449. **MOUNTING:** Rapid insert Push-on fastener, fixed to panel and printed board in one maneuver. **CONTACTS:** Male, machined brass alloy; female, machined high tensile phosphor bronze, gold over nickel, 5 amp. **INSULATOR:** Nylon resin. **SHELLS:** Steel or brass, tin plated (dimpled); zinc or cadmium plate with dichromate seal. **COUPLING:** Jackscrews and slide lock system. **NORMS:** Conforms to MIL-C-24308 and IEC 807-2, U.L. recognized.





HIGH DENSI-D

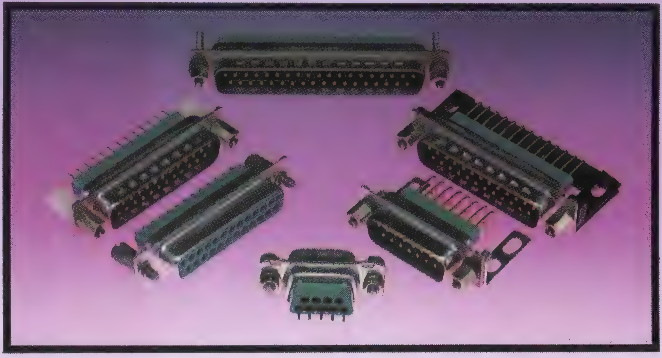
15 through 104 poles Sub-D Connectors

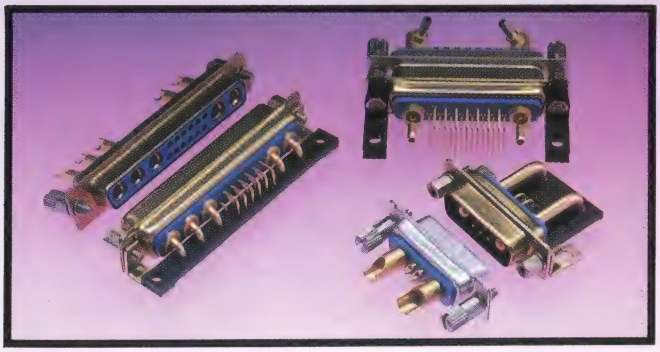
76% CONTACT DENSITY INCREASE: Qualified to MIL-C-24308 and U.L. recognized. **CONTACTS:** Removable, machined copper alloy, gold over nickel, 5 amp. "closed entry" female, MIL-C-39029. **TERMINATIONS:** Crimp, solder, printed board, straight or 90°. **INSULATOR:** Polyester glass, U.L. 94 VO, 6 variants of 15, 26, 44, 62, 78 and 104 poles. **SHELLS:** Steel or brass with tin plate (dimpled); zinc or cadmium plate with dichromate seal, stainless steel, passivated. **MOUNTING:** Panel and printed board. **COUPLING:** Jackscrews and slide lock system. **HOODS:** Metal, plastic. EMI/RFI.

FILTER-D

"Slim Line" Sub-D Filter Connectors

From 500pF to 30,000pF Capacitance. The internal planar ceramic filter permits the low profile "Slim-Line" design of the Positronic Filter-D Connectors. **HIGH RELIABILITY:** MIL-C-24308 and IEC 807-2 materials and conformance. **CONTACTS:** Male, machined brass alloy; female, machined high tensile phosphor bronze, gold over nickel, 5 amp. **TERMINATIONS:** Solder 24 AWG (0,25mm²) and 20 AWG (0,5mm²) printed board mount, straight and 90°. **INSULATORS:** DAP glass filled, 5 variants of 9, 15, 25, 37 and 50 poles. **SHELLS:** Steel or brass with tin plate (dimpled). **MOUNTING:** Panel and printed board. **COUPLING:** Jackscrews and slide lock system. **HOODS:** Metal and plastic. **INSERTION LOSS:** To 60dB.





COMBO-D

Coax, High Voltage, Power & Signal Contacts Sub-D Connectors

18 contact combination variants available within shell sizes, 1, 2, 3, 4, 5, 6

CONTACTS: Machined copper alloy, gold over nickel plating. Coaxial, High Voltage and Power contacts removable. Power contacts 10 to 40 amp. rated. Signal contacts 5 amp. rated. **TERMINATIONS:** Solder, printed board, straight or 90°. **INSULATOR:** Polyester glass U.L. 94 VO. **SHELLS:** Steel, zinc, cadmium or tin plated, stainless steel. **MOUNTING:** Panel and printed board. **COUPLING:** Jackscrews and slide lock systems. **HOODS:** Metal, plastic. **NORMS:** Conform to IEC 807-2 and MIL-C-24308.

POSITRONIC INDUSTRIES, INC.

423 N. Campbell • Springfield, Mo. 65801
Tel. 417-866-2322 • 800-641-4054 • Telex 436445 • Fax 417-866-4115

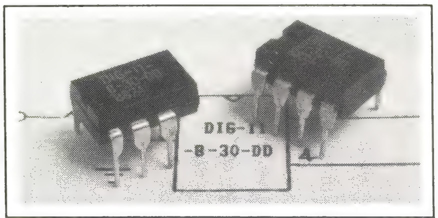
CIRCLE NO 49

tate, N Shields, Tyne and Wear NE29 8SE, UK. Phone 091-258-0690. TLX 53206. FAX 091-259-0997.

Circle No 393

Mosiac Semiconductor Inc, 742 Carroll Rd, San Diego, CA 92121. Phone (619) 271-4565. FAX 619-271-6058.

Circle No 394



MOSFET DRIVERS

- *Provide photovoltaic isolation*
- *Feature dynamic discharge circuitry*

The DIG-XX-8-30-DD Series of photovoltaic MOSFET drivers provide an isolated, optically coupled power source for driving the gates of power MOSFETs. The ICs feature dynamic-discharge (DD) circuitry that rapidly turns off the MOSFET when power to the input LED is interrupted. The DD feature also guarantees a break-before-make action in most solid-state relay applications. The ICs are available in single and dual versions. $3.95 and $6.45 (1000).

Dionics Inc, 65 Rushmore St, Westbury, NY 11590. Phone (516) 997-7474.

Circle No 395

MEMORY SUBSYSTEM

- *Integrates EPROM, static RAM, and decoders on a chip*
- *Provides software security in a user-programmable bit*

Featuring access times as fast as 40 nsec, the MAP168 Mappable Memory Subsystem contains a programmable mapping decoder, 32k bits of static RAM, and 128k bits of EPROM. You can configure the MAP168 for 8- or 16-bit data buses, yielding 16k bytes or 8k words of EPROM and either 4k bytes or 2k words of static RAM. You can address either the EPROM or the static RAM in blocks of 2k bytes or 1k word. The development tools are IBM PC compatible. The MAP168 is available in 40-, 45-, and 50-nsec versions, having 44 pins. You have a choice of J-bend plastic and ceramic leaded-chip carriers and ceramic leadless-chip carriers. Development system, including a 1-year extended software warranty, $1795; 45-nsec MAP168 in PLCC, $50 (100).

WaferScale Integration Inc, 47280 Kato Rd, Fremont, CA 94538. Phone (415) 656-5400. FAX 415-657-8495. TLX 289255.

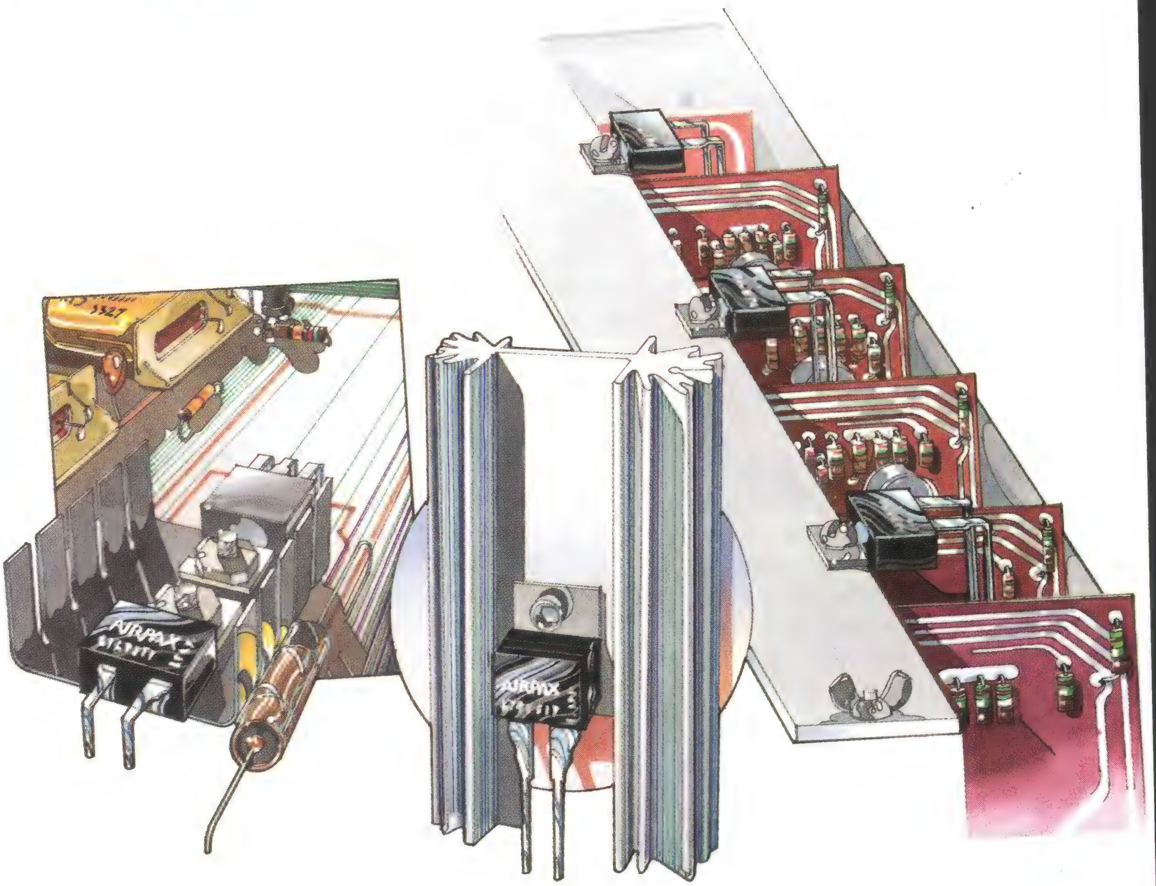
Circle No 396

NOW THERMAL PROTECTION COMES IN A TO-220 PACKAGE.

Airpax just put you in control of thermal management for your power supply with our new 6700 thermostat. The 6700 conforms to the dimensions of the international package standard Y220/TO-220. Enabling you to increase productivity with automatic, high-speed placement and soldering onto PC boards. Now you can eliminate the expensive hand placement and termination required with most power supply thermostats.

Featuring a bimetallic surface-sensing design, the 6700 thermostat also gives you virtually unlimited mounting capabilities, while providing accurate, responsive thermal protection from 40°C (104°F) to 120°C (248°F). And with gold plated silver contacts, the 6700 has a switching capacity from 5 VDC/1 Milliamp to 48VDC/1 Amp, or 120 VAC/1 Amp.

In design and performance, the 6700 TO-220 thermostat is completely new. Yet the Airpax innovation it brings to thermal management is not. If your power supply requires thermal protection that's accurate, dependable, and easily installed, let us provide the answer. Contact Airpax Company, Husky Park, Frederick, MD 21701. (301) 663-5141. A division of North American Philips Corporation.



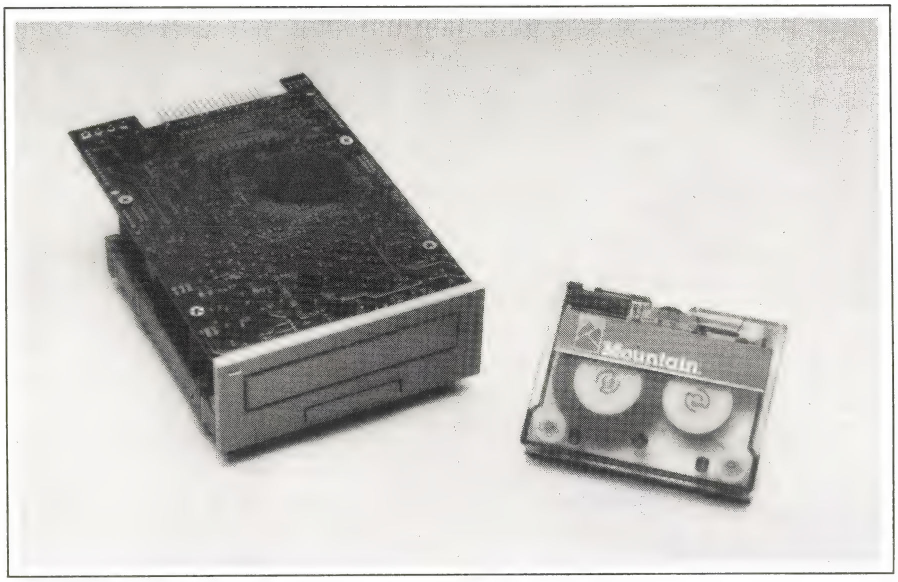
AIRPAX®
FREDERICK DIVISION

COMPUTERS & PERIPHERALS

TAPE DRIVES

- *Provide an 83M-byte storage capacity*
- *Operate at two transport speeds*

The TD8000 family of cartridge tape drives provides 83M bytes of formatted storage capacity. The units can operate at transport speeds of 2.2 or 4.4M bytes/minute. Designed for use with most IBM PCs and compatibles, the drives feature a floppy-disk-drive type of interface. Three drive configurations are available. The first is for internal installation in IBM PC/AT and PS/2 systems. The second is a stand-alone unit with power supplied by the system through a cable. The third drive is a self-powered, stand-alone unit. TD8000 drives incorporate a software-implemented error-correction code to increase data integrity; the drives' error rate is ≤1 error in 10^{14} bits read. From $695.



Mountain Computer Inc, 240 Hacienda Ave, Campbell, CA 95008. Phone (408) 379-4300. FAX 408-379-4302.

Circle No 400

DOS COMPUTER SYSTEM

- *Has a −40 to +80°C operating range*
- *Compatible with TTL and CMOS signals*

With an operating range of −40 to +80°C, the XTP DOS computer system suits environments with a wide temperature range. It consists of an STD DOS-equipped ZT 88CT08 single-board NEC V20 computer and a ZT 88CT25 expanded memory system; both are designed to work with TTL- or CMOS-based products. The ZT 88CT08 computer contains several IBM PC/XT peripherals and a 520k-byte onboard memory capacity. For ROM-based applications, you can purchase the ZT 88CT08 without the STD DOS operating system. In a ROM-based configuration, you can use real-time kernels such as VRTX, MTOS, and AMX to bring multitasking capability to STD Bus boards. You can use the ZT 88CT25 for expanded main memory or for RAM or ROM disk storage beyond the STD Bus's physical address limit of 1M byte of memory. $1455.

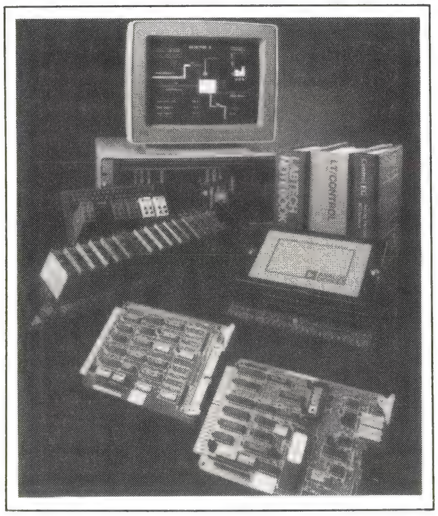
Ziatech Corp, 3433 Roberto Ct, San Luis Obispo, CA 93401. Phone (805) 541-0488. FAX 805-541-5088.

Circle No 401

I/O BOARDS

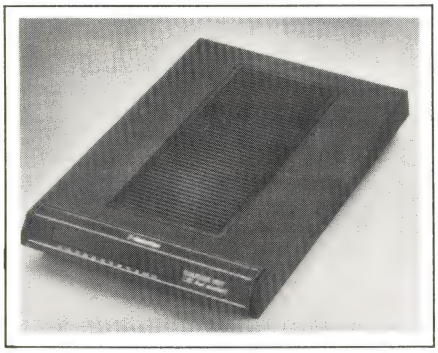
- *Offer IBM PC software compatibility*
- *Operate with the STD Bus*

The STD Bus data-acquisition boards offer IBM PC software compatibility. Using existing software drivers, the three boards mimic PC memory-mapping to bring DOS-based data-acquisition software to the STD Bus. Combined with four external signal-conditioning panels, the 12-bit RTI-1265 handles a maximum of 64 analog inputs with acquisition rates ranging to 19 kHz. The RTI-1266, a combination analog I/O model, provides the same input capability as the RTI-1265 *plus* 16 analog outputs updated at 400 Hz. The RTI-1267, a high-density, digital I/O version, features 24 digital I/O points addressed as three 8-bit ports, which you can configure as either inputs or outputs via software. All three boards operate from ±12V and 5V supplies. RTI-1265, $425; RTI-1266, $550; RTI-1267, $225.



Analog Devices Inc, Literature Center, 70 Shawmut Rd, Canton, MA 02021. Phone (617) 329-4700.

Circle No 402



MODEM

- *Meets both desktop and data-center needs*
- *Operates in two modes*

The Courier HST Dual Standard modem is compatible with all 2400-, 1200-, and 300-bps modems and all MNP Class 1-5 error-checking and data-compression modems. In both the proprietary HST and V.32 operating modes, the modem transmits asynchronous and synchronous data at 9.6, 7.2, and 4.8k bps. In the V.32 mode, it also receives data at the same rates. At 2400 and 1200 bps, the Dual Standard modem is compatible with CCITT V.22 modems; at 1200 bps, it is also compatible with Bell 212A modems; and at 300, it is compatible with CCITT V.21 and Bell 103 modems. The unit uses a standard auto-dialing command set to provide compatibility with all μC data-communications software. $1595.

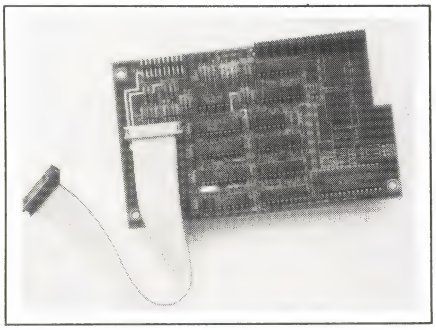
US Robotics Inc, 8100 N McCormick Blvd, Skokie, IL 60076. Phone (312) 982-5010.

Circle No 403

INTERFACE BOARD

- *Brings ANI flexibility to voice processing*
- *Detects and generates 15 multi-frequency tones*

The MF/40 interface board allows IBM PC-based voice-processing systems to generate and detect multifrequency tones, which are used in interswitch communications such as telephone companys' automatic number identification (ANI) circuits. The MF/40 is a daughter-board assembly that connects to the vendor's Dialog/4X voice-processing board via internal digital- and audio-expansion buses. As a result, it does not occupy any IBM PC bus slots. The board detects and generates the full set of 15 MF tones. The MF/40 software, which comes with the board, includes a device driver that you can install and features dial and receive commands



that are fully compatible with the existing D/4x DTMF dial and receive commands. The company's D40CHK D/4x software provides the diagnostic analysis capability for the MF/40. From $1195.

Dialogic Corp, 129 Littleton Rd, Parsippany, NJ 07054. Phone (201) 334-8450.

Circle No 404

DISK DRIVES

- *Offer 125M-byte capacity*
- *Feature an imbedded SCSI interface*

The MK-230 Series of 3½-in. Winchester disk drives offers capacities ranging to 125Mbytes. The drives feature an embedded SCSI interface to ease the integration process. They have a 25-msec average seek time and a 10M-bps data transfer rate. The units employ a dedicated landing zone, which ensures data integrity by protecting previously stored data. On power down, the heads automatically retract to the dedicated landing area, thereby preventing data loss due to shock and vibration. The drives require 10W of power. An optional adapter kit lets you install the drives in systems with half-height, 5¼-in. slots. Host adapters and driver software are also available. 125M-byte model, $795 (OEM qty).

Toshiba America Inc, Disk Products Div, 9740 Irvine Blvd, Irvine, CA 92718. Phone (714) 583-3108.

Circle No 405

TRANSCEIVER

- *Operates in encrypted and nonencrypted modes*
- *Transmits at 2400, 4800, or 9600 bps*

The SV9600-S still video transceiver sends and receives continuous-tone color video images in both

encrypted and nonencrypted modes. In its encrypted mode, the transceiver transmits at either 2400 or 4800 bps, depending on the type of STU-III voice/data telephone-encryption terminal you use. In its nonencrypted mode, the transceiver operates over standard telephone lines at 9600 bps. The transceiver accepts input from a wide variety of still and motion video

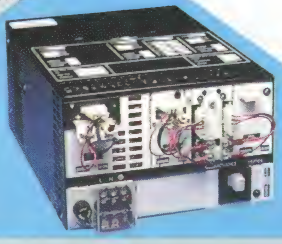
CIRCLE NO 44

You design the product.

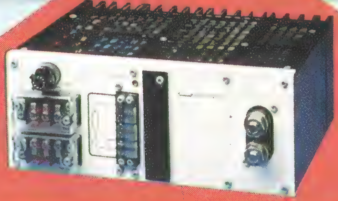
Let Advance supply the power.

5/300 High Power — 5″ x 8″ x 11″ ■ 5V/300A/1500 watts ■ Built-in load sharing and paralleling circuit.

Powerflex — Up to 5 outputs ■ 500 watts continuous /750 watts surge ■ Inputs of 115/230 VAC or 48 VDC

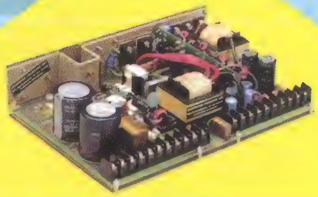


Hiflex — 5″ x 8″ x 11″ ■ Up to 6 independent outputs ■ To 1000 watts



MG — Demonstrated MTBF in excess of 125,000 hours ■ Single outputs from 5V-60V/100 watts to 500 watts ■ High-density convection cooled packaging

Multi High Power — 5″ x 8″ x 11″ ■ Mix and match up to 5 outputs ■ To 1000 watts



Open Frames — 100 KHZ high-efficiency switching ■ Cost effective ■ Multiple outputs

The electronic systems you design are complicated enough without designing your own DC switching power supply — a system in itself. So go ahead. Do what you do best. And let Advance supply the power.

When designing around any one of the single- or multiple-output, open or closed Advance switching power supplies, you won't have to worry about compromising the overall quality of your product. These reliable switchers deliver from 180 to 1500 watts of full power in any voltage combination you may require.

Built to the highest standards, these units meet UL, CSA, VDE, IEC, and FCC requirements. With MTBF ratings that generally exceed others in their class.

When you need precise, dependable power for a well-designed instrument, computer or control, call 1-216-349-0755 for more information.

Advance Power Supplies
32111 Aurora Road
Solon, OH 44139

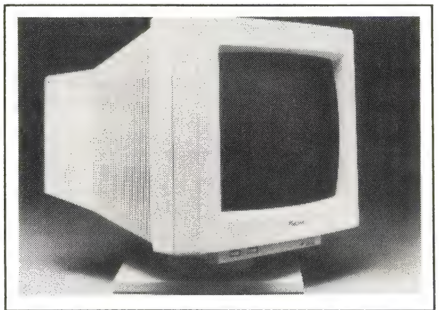
ADVANCE POWER SUPPLIES

CIRCLE NO 43

sources, and it can display the images on a color video monitor. By using the company's color video printer, you can also obtain hard-copy prints from the transceiver. $14,400.

Eastman Kodak Co, Electronic Photography Div, Rochester, NY 14650. Phone (800) 445-6325.

Circle No 406



MAC COLOR MONITOR

- *Scans at 35 kHz*
- *Has an unlimited color capacity*

The Model RE1475 14-in. analog monitor for the Macintosh scans horizontally at 35 kHz interlaced and has a resolution of 640×480 pixels. It measures 15×14.2×14.9-in. and weighs 27.6 lbs. It has a nonglare dark-tint screen, and its ergonomically designed cabinet has 25° of tilt and 180° of swivel. The screen display has a dot pitch of 0.31 mm with 90° of deflection. The geometric distortion is <1%. The monitor has an unlimited color capacity and comes with a 2-year warranty. $645.

Relisys, 320 S Milpitas Blvd, Milpitas, CA 95035. Phone (408) 945-1062. FAX 408-945-0587.

Circle No 407

GRAPHICS ADAPTER

- *Meets a variety of display standards*
- *Supports digital and analog monitors*

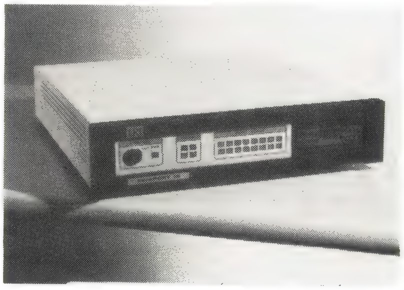
The QuadVGA Spectra graphics-adapter card supports 640×480-and 800×600-pixel extended VGA standards and can be upgraded to support the emerging 1024×768-pixel super-extended VGA resolutions. The board can fit in either an 8- or 16-bit slot. It is equipped with both a 9- and a 15-pin connector to support digital and analog monitors, respectively. The adapter enables analog monitors to display low-resolution graphics such as CGA, EGA, MDA, and Hercules. The board provides 256k bytes of 100-nsec RAM, which you can upgrade to 512k bytes. A high-speed BIOS enables increased display performance. The board comes with a VGA-compatible connector and documentation. $549.

Quadram, One Quad Way, Norcross, GA 30093. Phone (404) 923-6666.

Circle No 408

TERMINAL SERVER

- *Allows terminals to operate with Ethernet protocols*
- *Supports as many as 16 terminals and 64 sessions*



The Intraport-16+ multiprotocol Ethernet terminal server allows you to use the same terminal for sessions on Ethernet hosts running Transmission Control Protocol/Internet Protocol and DEC VAX hosts running VMS. For hosts running TCP/IP, the server supports "telnet" and "rlogin" session establishment. For VAX/VMS hosts, it supports the LAT terminal-access protocol. The Intraport-16+ can serve as many as 16 physical terminals, allowing each terminal to simultaneously support as many as four sessions using any permutation of the available protocols. £5000.

Logic Replacement Technology Ltd, 7 Arkwright Rd, Reading, Berkshire RG2 0LU, UK. Phone (0734) 311055. TLX 847395.

Circle No 409

MODEM

- *Operates at 9600 or 2400 bps*
- *Features automatic changeover between leased and dial-up lines*

Suitable for use on leased or dial-up telephone lines, the Delta-32 modem operates in either V.32 (9600 bps) or V.22bis (2400 bps) modes. The modem can handle synchronous or asynchronous communications protocols and has autodial and autoanswer facilities. In the event of leased-line failure, the modem will automatically switch over to a dial-up line to maintain the communications channel. It accepts Hayes AT, Racal-Milgo, and V.25bis command sets and has a separate control port that allows you to configure and control the modem from an asynchronous terminal without disturbing the data channel. Several standard modem configurations are stored in nonvolatile memory within the modem. The Delta 32 is available in either desk-top or rack-mount versions. £945.

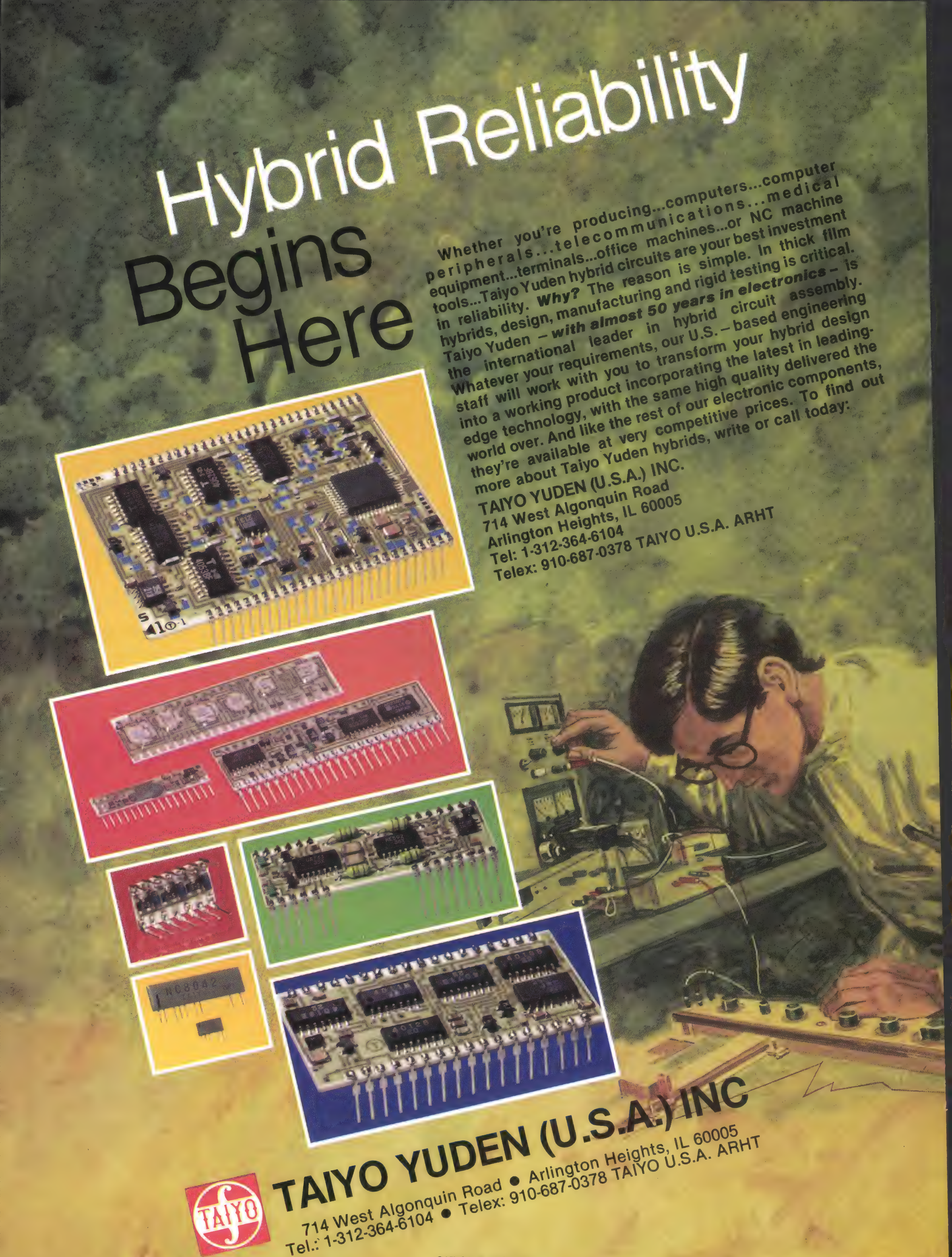
Racal-Milgo Ltd, Landata House, Station Rd, Hook, Hampshire RG27 9JF, UK. Phone (025672) 3911. FAX 025672-4717.

Circle No 410

Racal-Milgo Intercontinental Inc, Box 407044, Fort Lauderdale, FL 33340. Phone (305) 475-1601. FAX 305-476-4942.

Circle No 411

CIRCLE NO 39



Hybrid Reliability
Begins
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CIRCLE NO 38

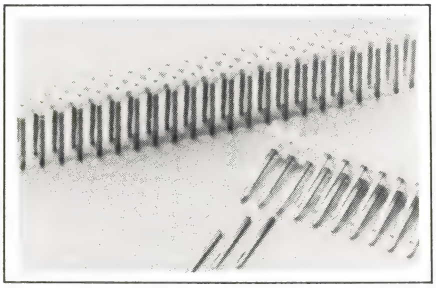
DISPLAY

- *Features a 640×400-pixel resolution*
- *Employs a detachable backlighting system*

The TLX-1501-C3M monochrome supertwist LCD uses a thin polymer retardation film as a compensating cell to replace the extra layer of glass found in conventional supertwist displays. This design provides a contrast that's greater than 12:1. The display employs a detachable fluorescent backlighting system to maximize serviceability. The display resolution equals 640×400 pixels and the dot pitch is 0.33×0.33 mm. The unit measures 320×197.4×22 mm and weighs approximately 700g. $646.

Toshiba America Inc, Electron Tubes and Devices Div, 1 Parkway N, Suite 500, Deerfield, IL 60015. Phone (312) 945-1500.

Circle No 351



CONNECTORS

- *Feature a low profile*
- *Have 0.1-in. pin spacings*

D-Peg pc board connectors feature detachable insulators to provide a low profile for close board-to-board applications. D-Peg is a pin strip with the pins retained by an insulator at the top of the interface. The rounded pin tails fit into 0.031-in. plated through-holes in the board. A transition shoulder from the rounded tails to the 0.025-in. square pin stops the strip at the proper board-insertion depth. After wave soldering, the detachable insulator is removed. The connectors feature standard 0.1-in. centerline spacing and are available in single- and dual-row versions ranging to 40 and 80 pins, respectively. The pins are phosphor bronze with 10, 15, or 30 µin. of gold plating or 100 µin. of tin plating. $2.65 (1000) for a 50-position dual version.

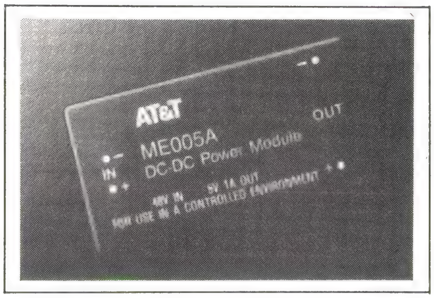
Crane Electronics, 4460 Lake Forest Dr, Cincinnati, OH 45242. Phone (513) 563-1161.

Circle No 352

POWER MODULES

- *Meet FCC Class A requirements*
- *Available with single, dual, and triple outputs*

ME005A, ME005BK, and ME025ABK power modules operate from a nominal 48V dc input and meet FCC Class A requirements. The ME005A provides a regulated 5V output rating; the ME005BK module outputs ±12V. Both these models have a 5W power rating. Model 025ABK delivers 25W from three outputs—5 and ±12V. The ME005A and the ME005BK modules measure 2×1.1×0.46 in.; the dimensions of the ME025ABK are 4.26×2.58×0.5 in. ME005A, $57; ME025ABK, $162.34.



AT&T Microelectronics, Dept 51AL230230, 555 Union Blvd, Allentown, PA 18103. Phone (800) 372-2447.

Circle No 353

UPSs

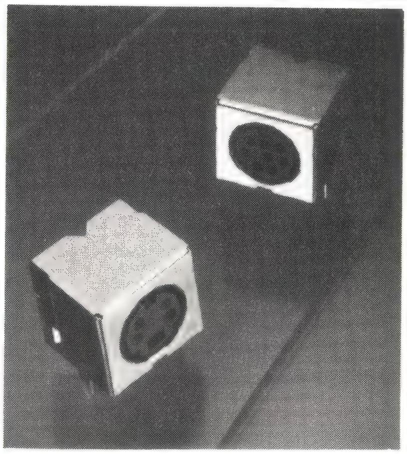
- *Provide standby power for PCs and LANs*
- *Can indicate line supply failure and battery exhaustion to a PC*

By utilizing thyristor switching techniques, the Power Lab H0 Series off-line uninterruptible power supplies can commutate between their line input supply and their internal lead-acid batteries in <10 nsec. This switching speed gives

them a performance comparable to on-line uninterruptible supplies. Targeted at users of personal computers and LANs, the series includes supplies with output ratings of 300, 600, 1000, and 1500 VA. They incorporate common-mode-rejection filters to smooth out harmonic fluctuations in the line input supply, and they provide full protection against voltage spikes, voltage sags and surges, brown-outs, and black-outs. Depending on the connected load, the internal batteries provide between 10 and 30 minutes of back-up power. A software option, which operates under MS-DOS, provides an onscreen window that indicates line input interruptions and the amount of battery back-up time remaining. When only one minute of battery back-up remains, the software automatically closes and saves to disk any open files in the personal computer. £395 to £1200.

Ondyne (UK) Ltd, Unit 4, Davenport Gate, W Portway Industrial Estate, Andover, Hampshire SP10 3SQ. Phone (0264) 66688. FAX 0264-66601.

Circle No 354



DIN CONNECTOR

- *500 mating-cycle life*
- *Is pc-board mountable*

A cube that houses a 3- through 8-position circular DIN insert is the keystone of this shielded connector. The right-angle, board-mountable receptacle connector mates with standard or latching-type cable connectors, using polarization and keying to ensure proper mating. The device incorporates controlled datum surfaces, gripper location, and contact-true position features for efficient robotic pickup and placement. The 94V-0 UL-rated housing will withstand vapor-phase or IR-reflow soldering processes. The connector uses phosphor bronze, nickel underplated contacts that are selectively gold plated on the mating end and tin lead plated on the solder tail. $1.50 (1000).

AMP Inc, Box 3608, Harrisburg, PA 17105. Phone (717) 564-0100. FAX 717-561-6179.

Circle No 355

"I'll measure, analyze, synthesize, model, test, document, provide solutions, and do just about everything else except

ask for a raise."

"I'm more than a test box, more than software. I'm the only complete frequency response analysis workstation in the business of servo control and power supply design.

I'm a master of stability analysis, because I test, model, synthesize, predict and verify *so* quickly. Imagine stabilizing loops in minutes, synthesizing feedback networks in seconds, and making Bode plots at the press of a button.

To optimize performance, you can connect up to three channels directly to an existing circuit and immediately plot frequency response. I'll then determine the compensation network needed to obtain the gain and phase margin you desire, at the frequency *you* choose–in seconds, not hours.

I can synthesize unlimited worst-case scenarios, predicting your design's performance each time. You get more design options from which to choose, so you'll be more confident in your decisions.

I do much more than optimize circuits. I'm great at characterizing components and networks, measuring input and output impedance and determining audio susceptibility. I allow you to create and analyze electronic and mathematical models, solve complex equations and generate root locus plots. I also do file math, including adding or deleting time delays, combining data files and converting transfer functions from open-loop to closed-loop response and back.

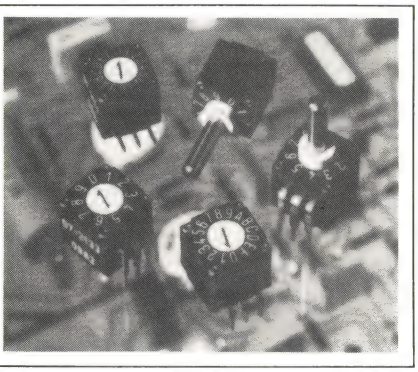
You'll do so much more because I do so much more. You'll become more efficient, productive, and valuable to your company, because you'll spend your time designing, rather than operating test equipment. See for yourself. Call **1-800-262-2522** (in California, **213-539-2522**) to ask for a demonstration.

I love to impress people with my abilities. Don't you?"

VENABLE Vi INDUSTRIES

Solutions that Speak for Themselves

CIRCLE NO 35



DIP SWITCHES

- *In shorting and nonshorting versions*
- *Hermetically sealed to accommodate washing processes*

Available with BCD, hexadecimal, and Gray code outputs, these coded switches come in shorting and nonshorting versions that can mount either vertically or horizontally. Readily stackable, the switches come with shaft- or screw-driver-type tuning mechanisms. The devices can switch 200 mA. The switch life equals 10,000 cycles and the operating range is −40 to +85°C. The switches are hermetically sealed and are washable. From $3.50 (100).

Elma Electronic Inc, 41440 Christy St, Fremont, CA 94538. Phone (415) 656-3400.

Circle No 356

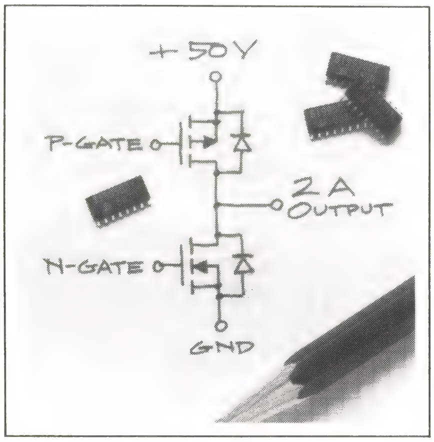
SENSOR SYSTEM

- *Features 500-ft transmission range*
- *Has 0.1-in. resolution*

The LGI-LMS-001 sensor system consists of an ultrasonic level sensor that has a range of 35 ft and a control unit. The control unit powers the sensor and receives the digital data from the sensor over a 50Ω coaxial cable, which can be as long as 500 ft. The control unit compares the data against register data set by the operator and uses the information to control one or two pumps or sound an alarm in case of trouble. An LCD readout indicates the liquid levels and the pumps that are operating. The control unit prompts the operator for six register settings including low-alarm, pump 1 turn-on, pump 2 turn-on, pump 1 turn-off, pump 2 turn-off, and a high-alarm setting. The system features a 0.25-in. accuracy, a 0.1-in. resolution, and a −40 to +60°C temperature range. Internal battery backup, remote alarm relay, and a 4- to 20-mA output are optional. $690.

Lagrange Instruments Inc, Kuchler Dr, LaGrangeville, NY 12540. Phone (914) 223-3336.

Circle No 357



HALF-BRIDGE DRIVER

- *Packs 2A into a surface-mount package*
- *Has a 2.3W dissipation*

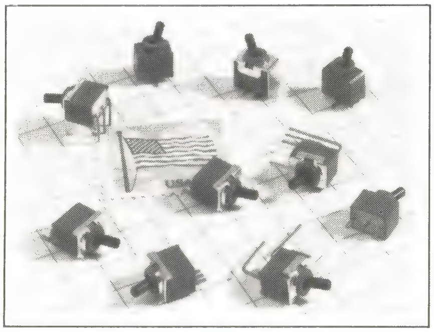
The Si9950DY half-bridge driver packs its 2A into a 16-pin small outline surface-mount package. The unit contains a complementary pair of 50V, low on-resistance (0.3Ω) MOS power transistors connected in a half-bridge configuration. A copper lead frame, specifically designed for this device, optimizes thermal performance in pc-board-mounted applications. Ten of the 16 leads connect directly to the back side of the die to improve heat transfer. As a result, the Si9950DY achieves a maximum power dissipation of 2.3W at a 25°C ambient temperature. $2.33 (100).

Siliconix Inc, 2201 Laurelwood Rd, Santa Clara, CA 95054. Phone (800) 554-5565, ext 1400.

Circle No 358

TOGGLE SWITCHES

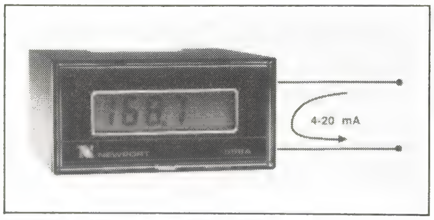
- *Sealed to accommodate cleaning processes*
- *40,000-cycle lifetime*



GT Series toggle switches withstand vapor-phase, IR-reflow, and wave-soldering methods and are sealed to eliminate flux intrusion during cleaning processes. Available in spst and spdt contact configurations, the units feature ultrasonically welded thermoplastic housings, which have a 94V-0 UL rating. Contacts are rated for 0.4 VA at 20V ac or dc. The switches' electrical life is 40,000 cycles at full load. Insulation resistance equals $10^9\Omega$ min and dielectric strength measures 1000V at sea level. Termination options include surface-mount and through-hole models with either 0.100-or 0.050-in. terminal spacing. From $2.31 (1000). Delivery, six weeks ARO.

C&K Components Inc, 15 Riverdale Ave, Newton, MA 02158. Phone (617) 964-6400.

Circle No 359



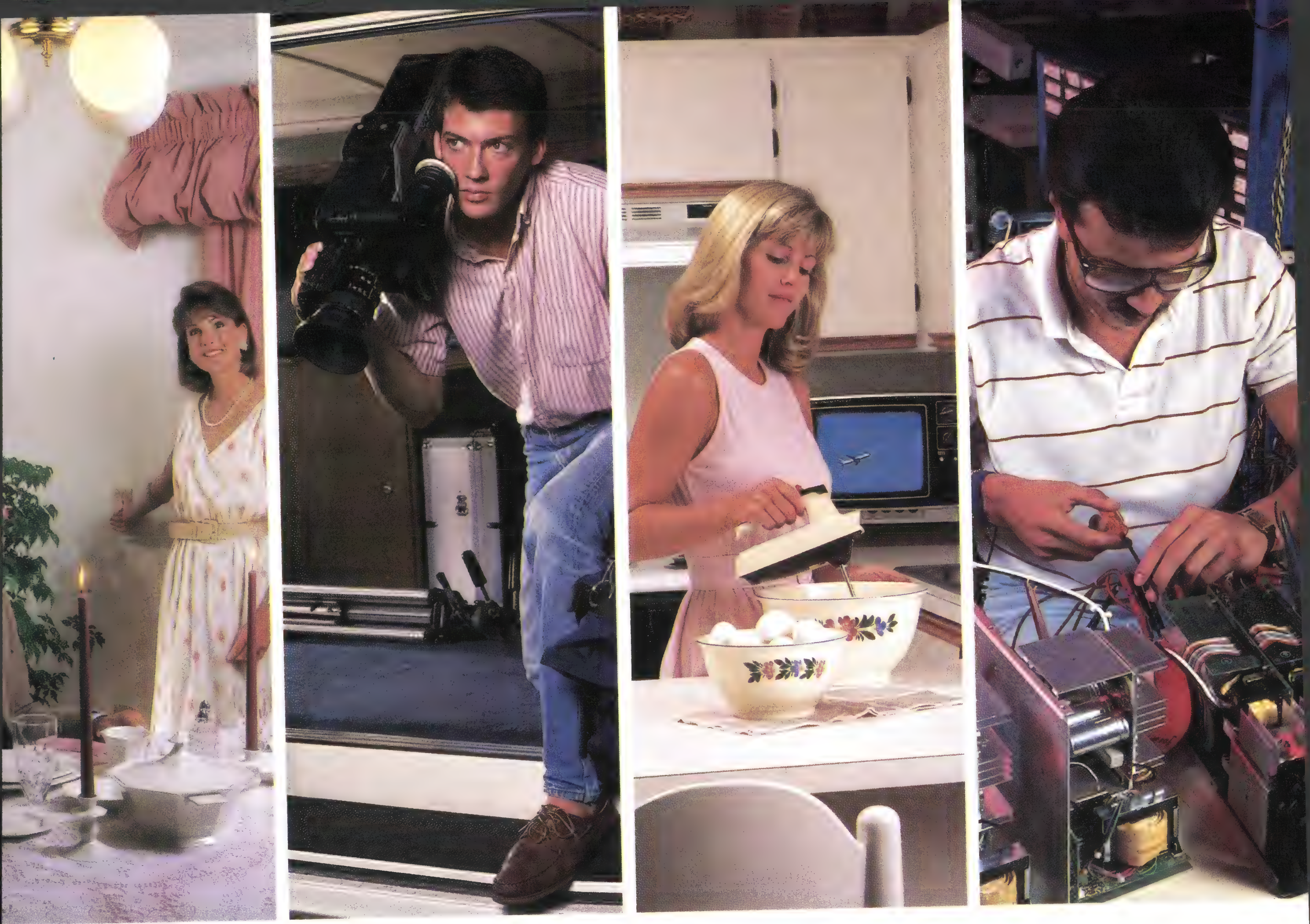
INDICATOR

- *Requires no external power*
- *Has an LCD readout*

The Model 558A 2-wire current-loop indicator accepts 4- to 20- or 10- to 50-mA process signals and digitally displays the process variable in percent or engineering units of pressure, flow, temperature, and level. The unit obtains its power directly from the current loop and can tolerate forward and reverse current overdrives of 200 and 1000 mA, respectively. The indicator's LCD readout can display from −1999 to +1999 or from −19990 to +19990 with a jumper-selectable dummy right-hand zero. Push-on jumpers and potentiometers scale the readout for percent or engineering units. The indicator is housed in a ⅛ DIN polycarbonate case. A NEMA-12-rated splashproof lens cover is optional. $160.

Newport Electronics Inc, 630 E Young St, Santa Ana, CA 92705. Phone (714) 540-4914. FAX 714-546-3022.

Circle No 360



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A DIVISION OF NORTH AMERICAN PHILIPS CORPORATION

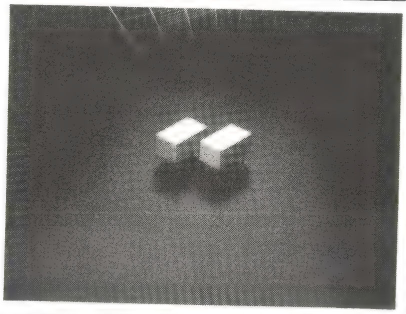
PHILIPS

CIRCLE NO 31

SWITCHING RELAY

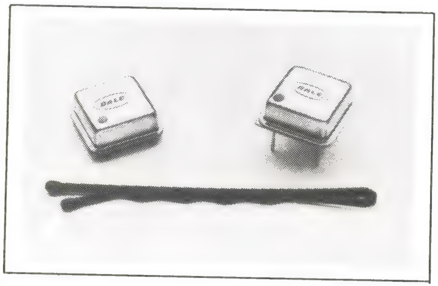
- *Features a 200-mW input sensitivity*
- *Offers 60-dB isolation*

The RK is a high-frequency switching relay with a 200-mW input sensitivity. A single-side stable device, the relay is sealed to accommodate dip-soldering processes. Nominal switching capacity is 10 mA at 24V dc. The 0.795×0.441×0.382-in. relay has a 1 Form C contact arrangement. Isolation at 1.5 GHz is 60 dB, and insertion loss at 900 MHz is 0.3 dB max. Coil voltage ratings range from 3 to 24V, and breakdown voltage between contact and coil measures 1000V rms. One- and two-coil latching-type relays are also available. $4.50 (500). Delivery, eight to 12 weeks ARO.



Aromat Corp, 629 Central Ave, New Providence, NJ 07974. Phone (201) 464-3550.

Circle No 361



OSCILLATORS

- *Available in through-hole and surface-mount models*
- *Offer ±0.005% accuracy*

Models XO-51B and XO-52B hybrid crystal clock oscillators are available in a through-hole version, and Models XOSM-51B and XOSM-52B come in surface-mount versions. All models are compatible with HCMOS, CMOS, NMOS, TTL, LSTTL, and STTL. All models have frequency ranges of 240 Hz to 1.5 MHz and 4 to 60 MHz with accuracies of ±0.005%, ±0.01% (standard), and ±0.05%. Rise and fall times are 10 nsec at CMOS levels and 6 nsec at TTL levels. The output capacitance is 50 pF for 1 to 10 TTL loads. Packaged in 0.5-in. square hermetically sealed cases, the oscillators are available in a choice of above-board heights ranging from 0.231 to 0.306 in. Model XO-52B, $3.81 (250). Delivery, 10 weeks ARO.

Dale Electronics Inc, 1122 23rd St, Columbus, NE 68601. Phone (602) 967-7874.

Circle No 362

Now You Can Think Big.

There's finally a *standard* line of 30 and 40 watt externals with Wide Range Input and you can plug 'em in anywhere in the world with no switches, no jumper cables:

WRI SERIES — **OUTPUTS**

MODEL	1	2	3
WRI 3011	+5v,6.0A		
WRI 3012	+12v,2.5A		
WRI 4214	+24v,1.75A		
WRI 3021	+5v,2A	+12v,1.5/2.5A	
WRI 4221	+5v,3A	+12v,2.5/4A	
WRI 3031	+5v,2A	+12v,1.5/2.5A	—12v,.5A
WRI 4231	+5v,3A	+12v,2.5/4A	—12v,.5A

But, If You Have To Think Small

We've got all the lower-power, lower-priced models with UL and CSA approvals as well:

WM SERIES — **OUTPUTS**

MODEL	1	2	3
WM075	+5v,1.5A		
WM144	+12v,1.2A		
WM112	+5v,800mA	+12v,600mA	
WM053	+5v,380mA	—5v,180mA	+12v,180mA
WM063	+5v,380mA	—12v,180mA	+12v,180mA
WM093	+5v,860mA	—5v,300mA	+12v,300mA
WM113	+5v,860mA	—12v,300mA	+12v,300mA
WM220-1	+5v,2.0A	+12v,500mA	—12v,500mA

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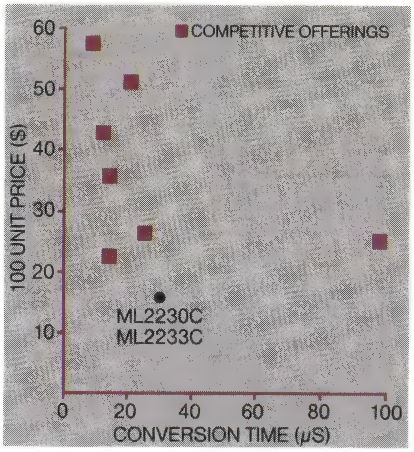
CIRCLE NO 30

NOTES FOR ANALOG SYSTEMS DESIGNERS

New price performance level attained with algorithmic 12-bit + sign A/D converters.

Micro Linear now has two 12-bit + sign A/D algorithmic converters that incorporate auto-zeroing circuitry and self-calibration; the ML2230, and the ML2233. This approach has no trimming and less circuitry, resulting in a lower price and an A/D converter that maintains accuracy over time.

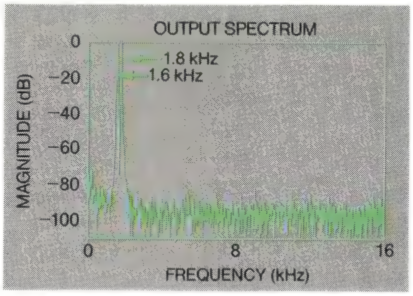
Priced at $15.95 in 100 unit quantities, both the standard 24-pin DIP ML2230, and the 28-pin DIP ML2233, include an internal sample-and-hold and an easy to use microprocessor interface.



12-bit A/D price/performance comparison including sample-and-hold cost.

Accuracy and Speed

Total conversion time is 31 microseconds, including the on-chip sample-and-hold acquisition time. Both devices can digitize a −2.5V to +2.5V sine wave at 12 kHz with a 73 db signal-to-noise ratio. Harmonic distortion is just 0.01%.

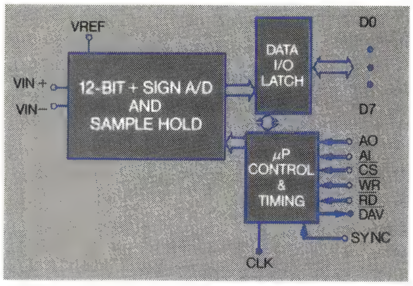


The FFT plot of the ML2233. A two tone, −2.5V to +2.5V, low distortion sine wave input.

All errors of the sample-and-hold are accounted for in the accuracy specification. Integral nonlinearity is ±½ LSB or ±1 LSB, there are no missing codes, and full scale and zero errors are less than ±1 LSB. This is over the temperature range, and with ±5% tolerance on +5V and −5V power supplies.

Versatility and Ease of Use

These 12-bit + sign A/D converters are designed for ease of use. The analog inputs can withstand 7V beyond the supplies. The high impedance analog input is differential for noise immunity and power supply rejection.



ML 2230 block diagram

These devices support several interface techniques: interrupt, DMA or polling. The ML2230 is designed to interface to an 8-bit microprocessor bus by outputting the data result in two 8-bit bytes. To interface to a 16-bit bus, the ML2233 provides a 13-bit data result. Both are designed to interface without additional components and are fully TTL and CMOS compatible. Bus timing parameters are compatible with the fastest microprocessors currently available.

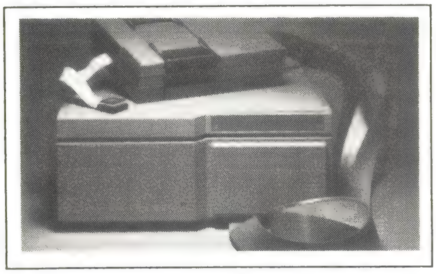
Call or Write for More Information

If your application calls for a 12-bit A/D converter or if you would like more information on Micro Linear's complete range of linear devices, please call (408) 433-5200 ext. 900 or write:

Micro Linear, Dept. TB,
2092 Concourse Drive,
San Jose, CA 95131.

Micro Linear

CIRCLE NO 27



IN-CIRCUIT EMULATOR

- *Supports 68030 in real time to 33 MHz*
- *Connects to host via 10M-bit/sec Ethernet port*

The EL 3200 in-circuit emulator performs transparent emulation at and above 33 MHz. It supports the 68030 µP at its maximum clock speed. The instrument is based on a family of stackable modules that will facilitate either reconfiguring for different processors or increasing the size of overlay RAM—a packaging concept that the vendor first introduced over a year ago in the EL 800 8-bit emulator. In the EL 3200, the modules complement an "assimilator" that measures 18.8×17.5×7.4 in. The emulator communicates at 10M bits/sec via Ethernet (or optionally, via a SCSI port) with its host, which can be a Sun, Apollo or VAX workstation, or an IBM PC-compatible computer. Trace memory is 16k frames of 144 bits; dynamic tracing is standard. The emulator can accommodate two overlay RAM modules, each of which can contain as much as 1M byte. Overlay RAM is mappable in 4k-byte increments. The number of breakpoints depends on the overlay RAM size; you can establish as many as 1M breakpoints. The Validate/XEL software includes a C cross compiler and assembly and high-level-language debuggers. The debuggers let you define symbols or use pre-defined ones. From $40,000; availability, third quarter 1989.

Applied Microsystems Corp, Box 97002, Redmond, WA 98073. Phone (800) 426-3925; in WA, (206) 882-2000. TLX 185196.

Circle No 420

DATA MONITOR

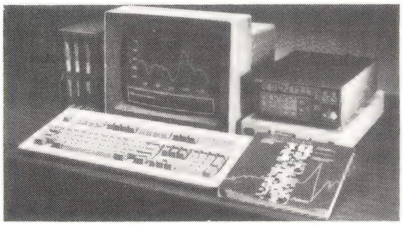
- *Analyzes Twinax network activity*
- *Plugs into an IBM PC or compatible computer*

Suitable for use on System-3X and AS/400 systems that use the Twinax 5250 interface protocol, the

TwinaxScope data monitor assists in the development, installation, and servicing of Twinax networks. Comprising an add-in board and software for IBM PC, PC/XT, PC/AT, or compatible computers, the instrument allows you to simultaneously monitor data transactions among as many as seven device addresses without affecting the integrity of the transferred data. Each transaction between the host computer and the monitored peripherals is time-stamped and recorded on the PC's disk as an MS-DOS file. You can then replay captured transactions to analyze system activity. The software provided includes search utilities that allow you to locate discrepancies or anomalies in the recorded data. £3995.

New Leaf Technology, 24A High St, Cobham, Surrey KT11 3EB, UK. Phone (0932) 66466. FAX 01-300-9601.

Circle No 421



IEEE-488 SOFTWARE

- *Runs on IBM PS/2 family as well as on PCs*
- *Supports 23 IEEE-488 interface cards from 14 vendors*

Asystant GPIB Version 1.01 is a software package that allows you to control IEEE-488-based instruments from computers in the IBM PS/2 family as well as from IBM PCs and 100% compatible machines. The software lets you control the external instruments interactively or through programs of your own design. It also facilitates analysis and graphic presentation of data obtained from the instruments. At present, the software supports 23 IEEE-488 interface cards supplied by 14 vendors: Advantech, B&C, BBS, Capital Equipment Corp, Contec, HP, IBM, ICS, IOtech, MetraByte, National Instruments, Qua Tech, Scientific Solutions, and Ziatech. $695.

Asyst Software Technologies Inc, 100 Corporate Woods, Rochester, NY 14623. Phone (716) 272-0070. FAX 716-272-0073.

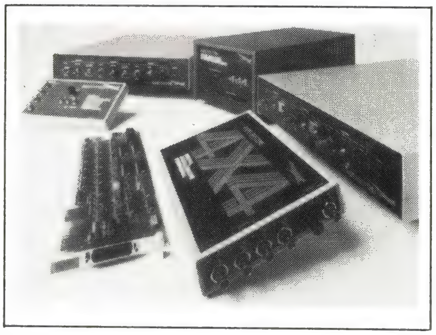
Circle No 422

SPECTRUM ANALYZERS

- *Use IBM PC or compatible for control*
- *Offer bandwidth to 10 MHz and resolution to 12 bits*

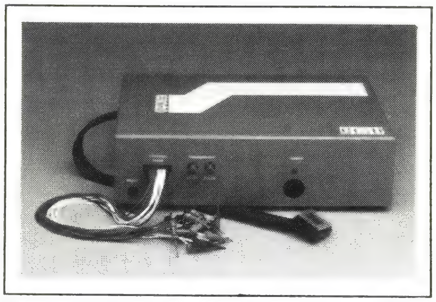
The R340, R350, R360 and R370 are spectrum analyzers that you can control from an IBM PC, PC/XT, PC/AT or a compatible computer. You can use the units as digital os-

cilloscopes, and they can save data to disk, display all channels simultaneously, and average spectra. The R340 has a single input, accepts signals from 500 Hz to 250 kHz, and digitizes to eight bits. The R350 has two inputs, accepts signals from 10 Hz to 500 kHz, and digitizes to 12 bits. The R360 is similar to the R340 except it has four inputs and accepts signals at frequencies as low as 10 Hz. The R370 is a 2-channel, 8-bit unit that accepts signals from 10 Hz to 10 MHz. R340, $1495; R350, $3995; R360, $2995; R370, $4995.



Rapid Systems Inc, 433 N 34th St, Seattle, WA 98103. Phone (206) 547-8311.

Circle No 423



68020 EMULATORS

- *Operate to 16.67 and 25 MHz*
- *Include two 136×4k-bit trace buffers*

Two units in the HMI-200 Series of in-circuit emulators support the 68020 microprocessor and provide real-time emulation. One emulator operates at 16.67 MHz, and the other runs at 25 MHz. You can expand the unit's 256k bytes of overlay memory to 2M bytes. The emulators provide four complex break and trigger points; four additional breakpoints, which work on simple addresses and ranges; and two 136×4k-bit trace buffers, which can record 16 external trace bits and 32 bits of time-tag information. The vendor also offers the Sourcegate software package to support high-level-language debugging and software-performance analysis. 16.67-MHz unit, $10,500; 25-MHz unit, $16,000; Sourcegate, $1500 for MS-DOS and $3000 for Unix; performance-analysis option, $2495 for 16.67-MHz unit and $3495 for 25-MHz unit. Delivery, 6 to 8 weeks ARO.

Huntsville Microsystems Inc, Box 12515, Huntsville, AL 35802. Phone (205) 881-6005. TWX 510-600-8258.

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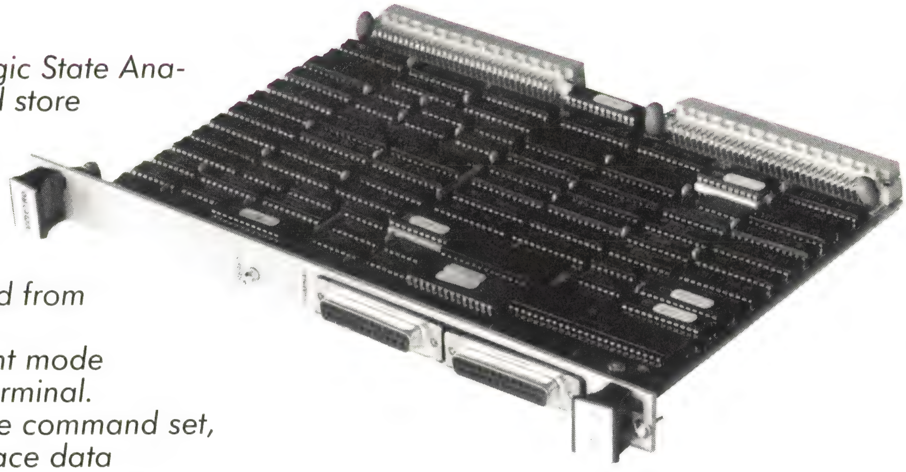

Logic State analysis

- 2 K Trace of 96 VMEbus signals.
- Bus Master Level stored with each sample.
- Powerful Triggers and Store qualifiers, including Bus Master Level.
- Time Tag showing relative or accumulated time.
- Powerful search in Trace memory.

```
    V M E b u s   T r a c e ,   group 1 of 3      Sampling mode : SYNC

         !  TIME      BUS  ADDRESS    DATA      R/W SIZE  STAT   IRQ*   IACK* AM EX
         !  rel.     LEVEL                                      7654321 OC IO
    -----!---------------------------------------------------------------------
==> TRIG !  00.0       0   00202EDC  xxxx4028   R  WORD   OK   1111111  1 1 3D 1
       1 !  3.22 us    0   00202EDA  xxxxFFF1   W  WORD   OK   1111111  1 1 3D 1
       2 !  0.49 us    0   00202EDC  xxxx402C   W  WORD   OK   1111111  1 1 3D 1
       3 !  4.71 us    2   402FFFFC  00200CE8   W  LONG   OK   1111111  1 1 3D 0
       4 !  256  us    2   40300000  FFF140DC   W  LONG  BERR  1111111  1 1 3D 0
       5 !  4.52 us    0   00202ECC  00202EFA   W  LONG   OK   1111111  1 1 3D 1
       6 !  1.79 us    0   00202EC8  FFF06916   W  LONG   OK   1111111  1 1 3D 1
       7 !  0.49 us    0   00202EC4  00200CE8   W  LONG   OK   1111111  1 1 3D 1
       8 !  0.49 us    0   00202EC0  0015000C   W  LONG   OK   1111111  1 1 3D 0
       9 !  0.79 us    3   126543E7  xxxxxx01   R  LBYTE  OK   1111111  1 1 3D 0
      10 !  0.68 us    3   126543E8  00200Cxx   R  UNAL3  OK   1111111  1 1 3D 1
      11 !  3.41 us    1   00200CF0  FFFB0040   R  LONG   OK   1111111  1 1 3D 1
      12 !  18.4 us    1   00200D0F  xxxxxx00   R  LBYTE  OK   1111111  1 1 3D 1
      13 !  21.2 us    1   00202ED8  xxxx02xx   W  UBYTE  OK   1111111  1 1 3D 0
      14 !  2.41 us    1   00202EBC  00000124   R  LONG   OK   1111111  1 1 3D 0
      15 !  0.68 us    1   00202EC0  0015000C   R  LONG   OK   1111111  1 1 3D 1

Time abs/rel:T    Group:1,2,3    Jump:J    Search:S    Print:ctrl-P    Quit:Q
```

Performance analysis

- Address distribution of eight user defined ranges.
- Bus Level distribution.
- Total VMEbus utilization.
- Bus Level utilization.

```
                    V M E b u s   D i s t r i b u t i o n

Total # of samples :    20480

Address ranges            0%  10%  20%  30%  40%  50%  60%  70%  80%  90% 100%

00000000-1FFFFFFF    12%  ******
20000000-3FFFFFFF     4%  **
40000000-5FFFFFFF    12%  ******
60000000-7FFFFFFF     9%  ****
80000000-9FFFFFFF    21%  **********
A0000000-BFFFFFFF    10%  *****
C0000000-DFFFFFFF     9%  ****
E0000000-FFFFFFFF    20%  **********

       Bus levels         0%  10%  20%  30%  40%  50%  60%  70%  80%  90% 100%

            3        36%  ******************
            2        20%  **********
            1        26%  *************
            0        16%  ********

Run: R                       Print: ctrl-P                              Quit: Q
```

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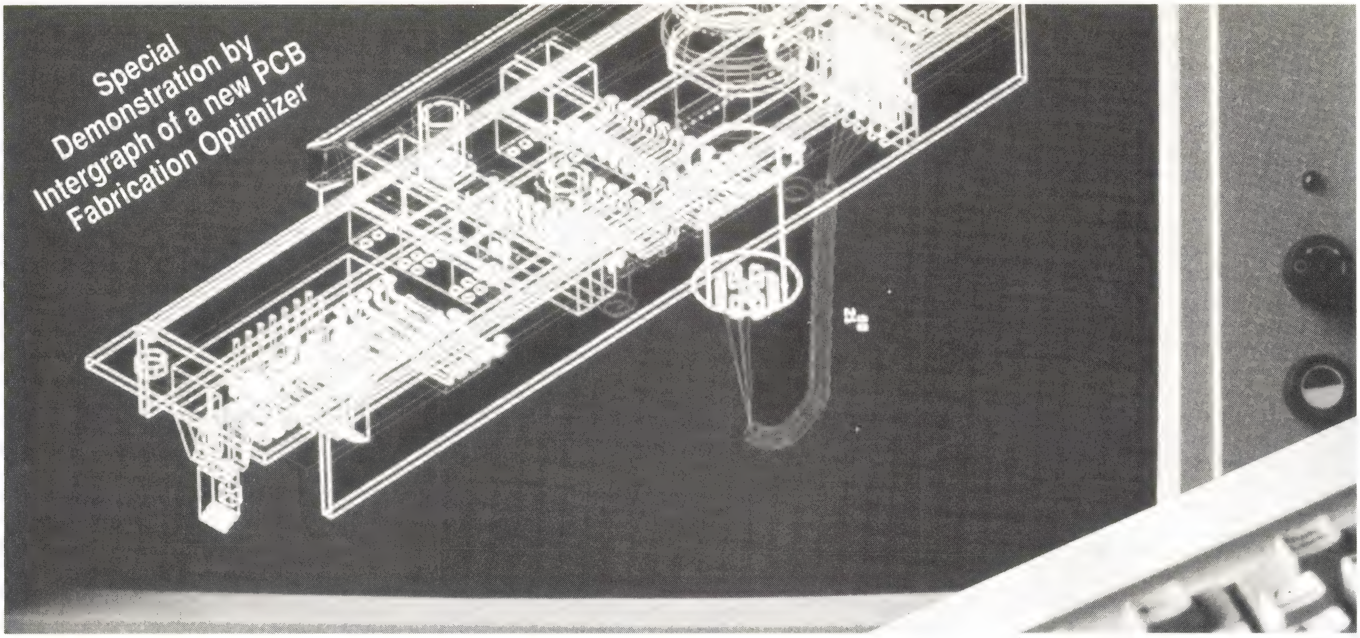
CIRCLE NO 21



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IntelligenceWare Inc, 9800 S Sepulveda Blvd, Suite 730, Los Angeles, CA 90045. Phone (213) 417-8896.

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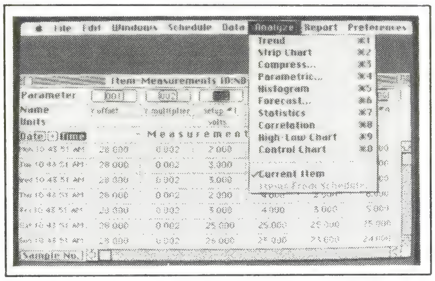

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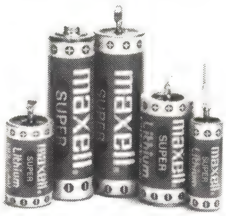

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National Instruments Corp, 12109 Technology Blvd, Austin, TX 78727. Phone (512) 250-9119. FAX 512-250-9319.

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Rebus Development Corp, 2330 B Walsh Ave, Santa Clara, CA 95051. Phone (408) 727-0110. FAX 408-263-3925.

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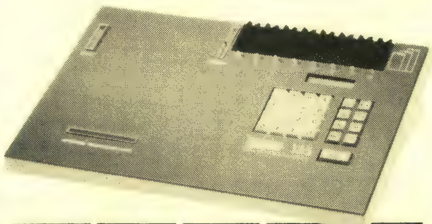

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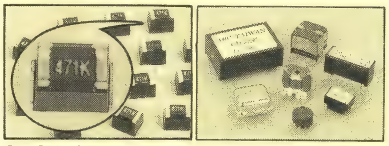

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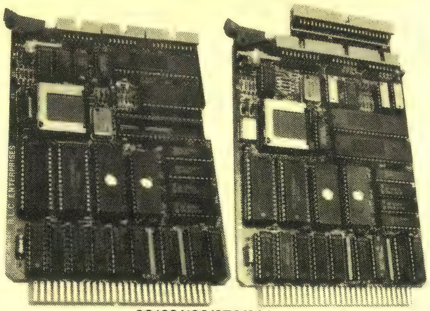

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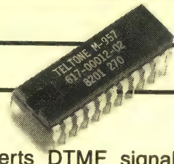

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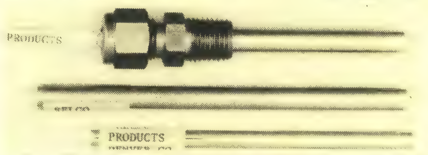

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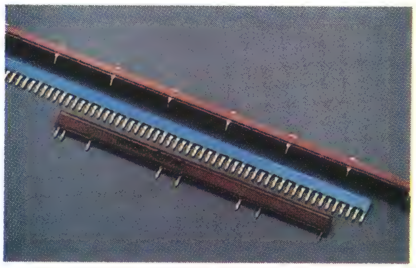

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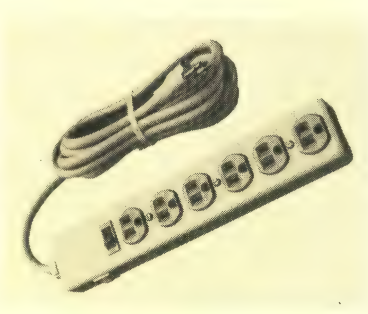

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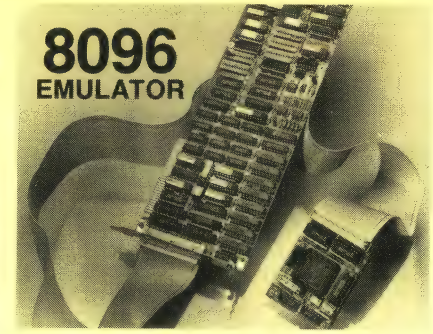

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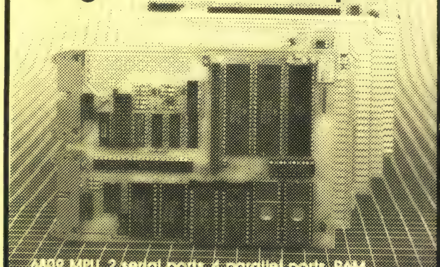

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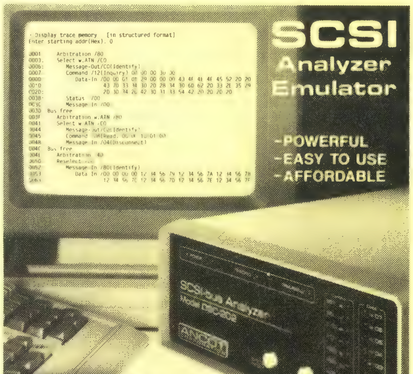

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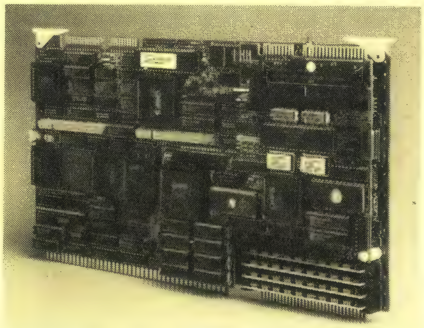

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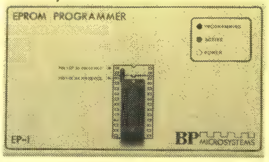

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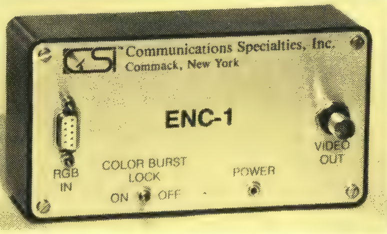

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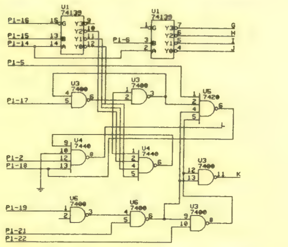

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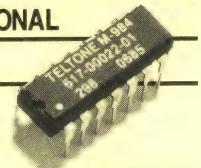

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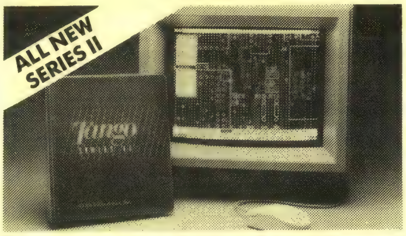

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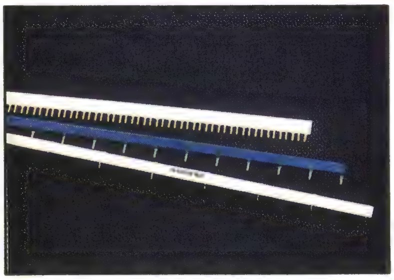

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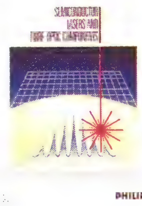

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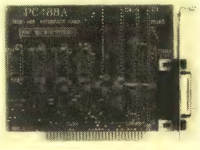

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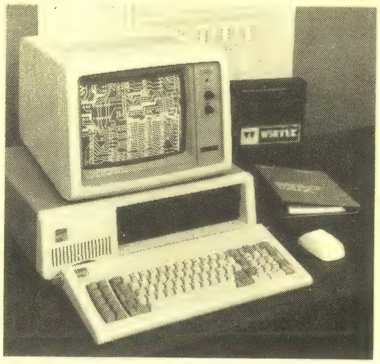

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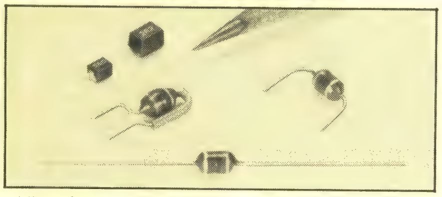

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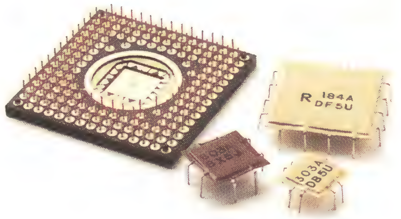

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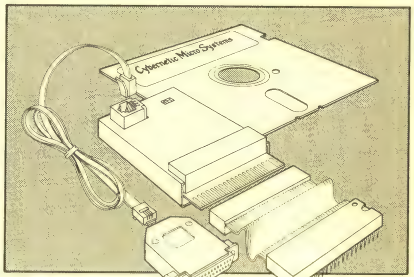

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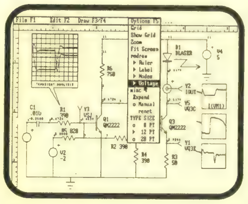

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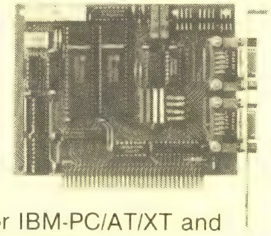

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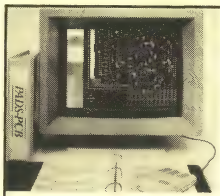

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Guide focuses on motion control and vision systems

The 10th anniversary edition of the vendor's product guide contains comprehensive data and price information on single-board computers, memory I/O cards, intelligent motor controller ICs and boards, dual-axis chopper design, and high-power driver cards. Also described are video cross-hair generators and digitizers, programmable cross-hair generators, and high-power driver cards.

Advanced Micro Systems Inc, 31 Flagstone Dr, Hudson, NH 03051.

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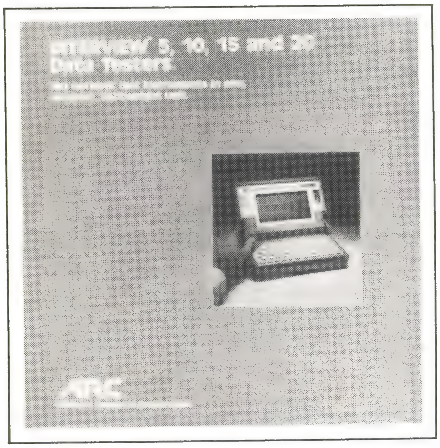

Brochure describes data testers

The company's brochure highlights the features and specifications of the Interview 5/10/15/20 Series of compact, multifunction data testers. The publication summarizes the units' applications for field-service personnel, data-communications technicians, and installation crews, and describes how a single unit performs the functions of 10 different test instruments, such as data-line monitors and protocol analyzers/emulators.

Atlantic Research Corp, Teleproducts Div, 7401 Boston Blvd, Springfield, VA 22153.

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STD Bus development system

The vendor's 36-pg catalog *PC/XT on the STD Bus* outlines the STD-XT line of microcontrollers, peripherals, and accessories. The publication provides technical information about the STD-XT CPU card, support card, floppy-disk card, and hard-disk drive. It also discusses STD-XT development systems and related accessories.

Octagon Systems Corp, 6510 W 91st Ave, Westminster, CO 80030.

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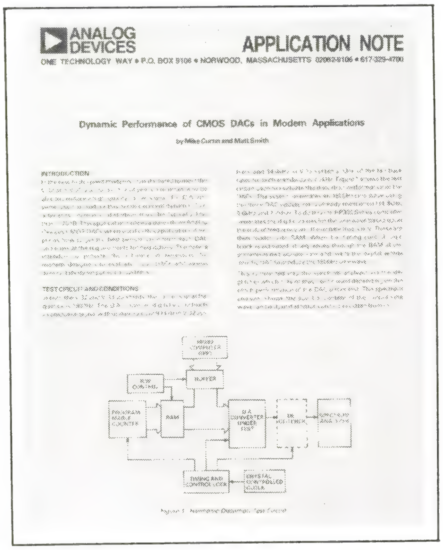

Selecting DACs for high-speed modem designs

The 6-pg application note describes how you can select, use, and evaluate CMOS D/A converters in high-speed modem designs. Using the vendor's DACs, the note gives examples of test setups and an analysis of measured characteristics. The discussion also examines the harmonic distortion test circuit, methods of generating test signals, appropriate sampling rates, filtering, and the need for a deglitcher in some tests. Oscilloscope photos show the overall spectral response of the DACs under various test conditions.

Analog Devices Inc, Literature Center, 70 Shawmut Rd, Canton, MA 02021.

Circle No 378

Book tells you how to simulate with Spice

According to the vendor, *Simulating With Spice* is the most comprehensive book available for learning the analog-circuit simulator, Spice. It contains a complete syntax reference guide for all Spice (Berkeley Spice 2G6) commands, elements, statements, and analysis capabilities. The tutorial section contains 12 problems and guides the user through each simulation. The section on advanced techniques and debugging allows the simulation specialist to delve deeper into Spice's operation. Finally, the book features an entire section of application notes, appendices containing netlists for each example in the tutorial section, an index, and a bibliography of more than 130 related references listed by topic. $65.

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Mar. 16	Feb. 23	CAE, Analog ICs	Closing: Mar. 3 Mailing: Mar. 23
Mar. 30	Mar. 9	Integrated Circuits, Computer Boards	Closing: Mar. 17 Mailing: Apr. 6
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Apr. 27	Apr. 6	Communications Technology, Special Issue Communication ICs	Closing: Apr. 13 Mailing: May 4

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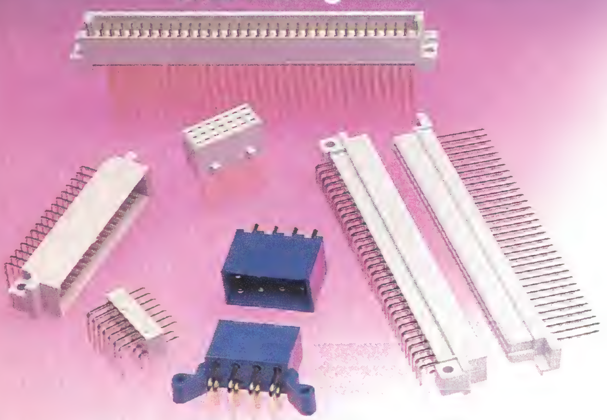

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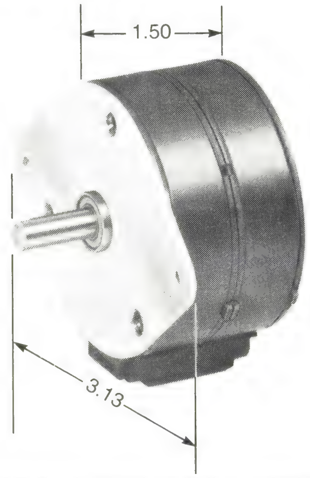

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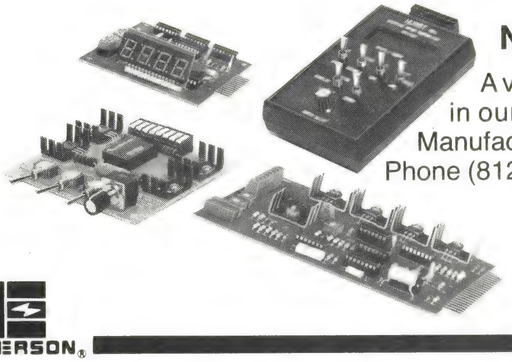

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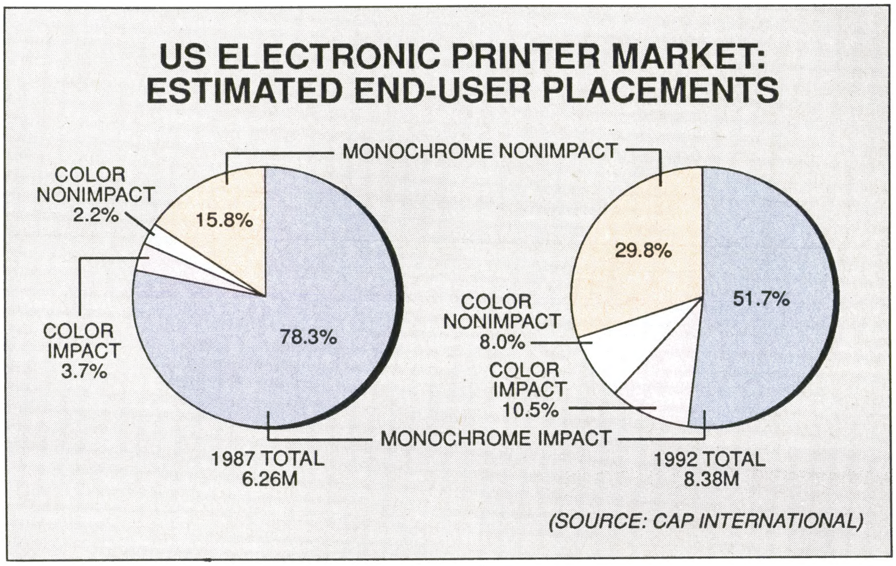
Color makes inroads into printer market



Although the use of color in office documents has been very limited to date, demand for color should increase over the next few years, growing at a compound annual rate of 35% for the forecast period from 1988 to 1992, according to CAP International (Norwell, MA). The market research company sees in the products introduced over the past years some significant trends in the color-printer market that will encourage broader demand: Image quality, for example, has improved. Compatibility with various operating systems has increased, and there's more text and graphics integration. In addition, vendors have developed more application software. Color copiers are also going to be more easily available.

The highest growth sector for color hard copy will center on workstation and office use for the production of business and presentation graphics. (Desk-top publishing will have an influence as well.) CAP estimates that US sales for color impact printers will approach 880,000 in 1992, up from 232,000 in 1987; sales for nonimpact color printers should reach 670,000 units in 1992, up from about 138,000 in 1987. The total US printer market should be about 8.38 million units by 1992.

Monolithic op amps to reach $800M by 1992

Monolithic devices continued to dominate the op amp market last year, claiming 92.8% of the market, according to Venture Development Corp (Natick, MA). Manufacturers will continue to improve the performance of monolithic op amps, and the devices' market share should continue to increase as a consequence. The primary advantages of monolithic op amps over hybrid ones include lower cost and smaller size; in general, they are also more easily available and offer shorter lead times as well. Shipments of monolithic op amps are expected to increase at an average annual rate of 10.9% through 1992.

VDC estimates that the 1988 market for hybrid devices was worth $41.2 million. Manufacturers of those devices target specialized corners of the market where very high performance is needed. Usually, hybrids are found in applications that require high speed or high power, or both. Other niches include those that demand low noise and low bias current. Although their market share should decrease somewhat over the next few years, total shipments will increase. Revenues for hybrid op amps should grow at an average annual rate of 7.1% and gross $53.5 million in 1992.

VDC also analyzed the market for monolithic op amps according to process technology. Bipolar devices, which include those with JFET inputs, accounted for $392 million in 1988, which represented 73.8% of all monolithic op-amp shipments. VDC found that almost all general-purpose op amps were manufactured using bipolar techniques. Furthermore, bipolar parts have entered many specialty areas, including applications that require low offset voltage, low bias current, low noise, low voltage drift, high speed, high power, and military grade. The bipolar parts are attractive alternatives because of reliable technology and low cost.

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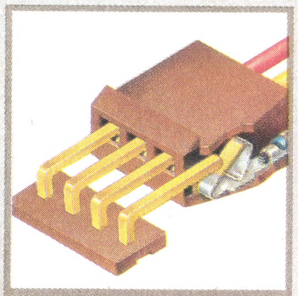

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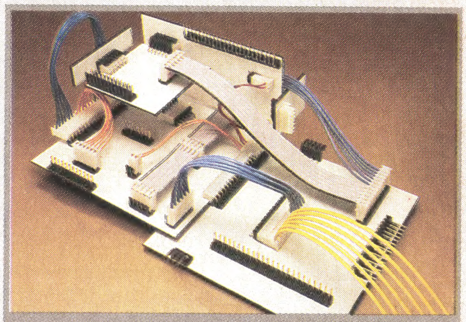

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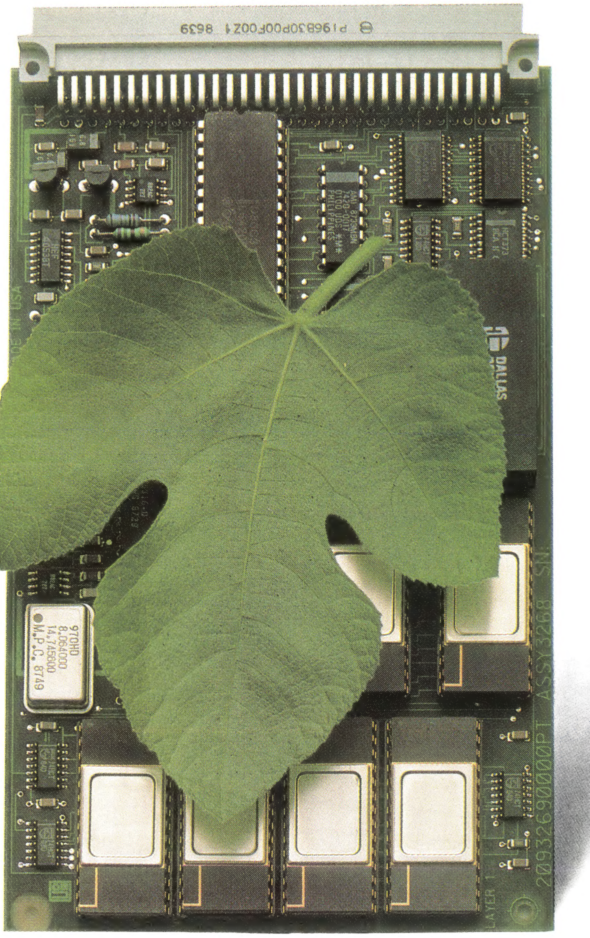

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While the data pump is functionally identical to the industry standard UDS V.32 modem, it has been stripped of its on-board power supply and DAA. These functions can be easily imported via the board edge connector.

For the bare facts about technical details and quantity pricing, contact Universal Data Systems, 5000 Bradford Drive, Huntsville, AL 35805. Telephone 205/721-8000; Telex 752602 UDS HTV.

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